US007976139B2

(12) **United States Patent**
Kyoso et al.

(10) **Patent No.: US 7,976,139 B2**
(45) **Date of Patent: Jul. 12, 2011**

(54) **LIQUID EJECTION HEAD AND LIQUID EJECTION APPARATUS**

(75) Inventors: **Tadashi Kyoso**, Kanagawa-ken (JP); **Masakazu Okuda**, Ebina (JP)

(73) Assignees: **Fujifilm Corporation**, Tokyo (JP); **Fuji Xerox Co., Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 819 days.

(21) Appl. No.: **12/031,577**

(22) Filed: **Feb. 14, 2008**

(65) **Prior Publication Data**

US 2008/0198208 A1 Aug. 21, 2008

(30) **Foreign Application Priority Data**

Feb. 16, 2007 (JP) 2007-037015

(51) **Int. Cl.**
B41J 2/175 (2006.01)

(52) **U.S. Cl.** **347/85**; 347/89

(58) **Field of Classification Search** 347/85–87, 347/89–90, 17, 68
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2003/0011668	A1*	1/2003	Yoshida	347/86
2008/0136860	A1*	6/2008	Kyoso	347/19
2008/0198207	A1*	8/2008	Katada	347/85
2008/0211841	A1*	9/2008	Kojima et al.	347/9
2008/0238980	A1*	10/2008	Nagashima et al.	347/17
2008/0309739	A1*	12/2008	Takahashi	347/85

FOREIGN PATENT DOCUMENTS

JP	10-114081 A	5/1998

* cited by examiner

Primary Examiner — Ellen Kim
(74) *Attorney, Agent, or Firm* — Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

A liquid ejection head includes: a plurality of nozzles which eject liquid; a plurality of pressure chambers connected respectively to the plurality of nozzles; a common flow channel which is provided to be shared by the plurality of pressure chambers and has a plurality of supply flow channel connection ports and a plurality of circulation flow channel ports; a plurality of supply flow channels through which the liquid flows from the common flow channel to the plurality of pressure chambers via the plurality of supply flow channel connection ports; and a plurality of circulation flow channels through which the liquid flow from the plurality of pressure chambers to the common flow channel via the plurality of circulation flow channel ports, wherein the plurality of supply flow channel connection ports and the plurality of circulation flow channel ports are arranged so that a pressure differential of the liquid between the supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber is equal in respect of all of the plurality of pressure chambers.

12 Claims, 18 Drawing Sheets

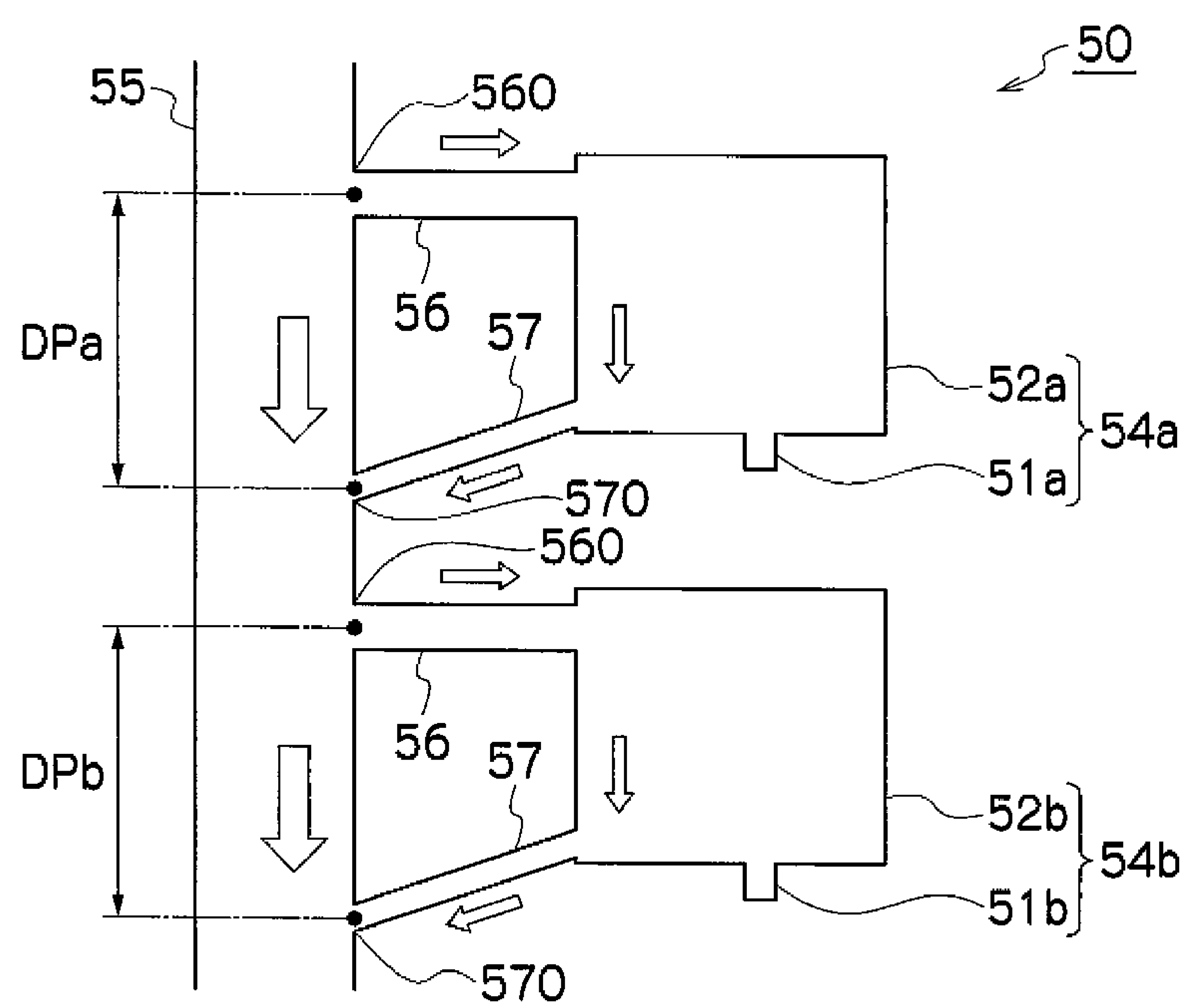


FIG.1

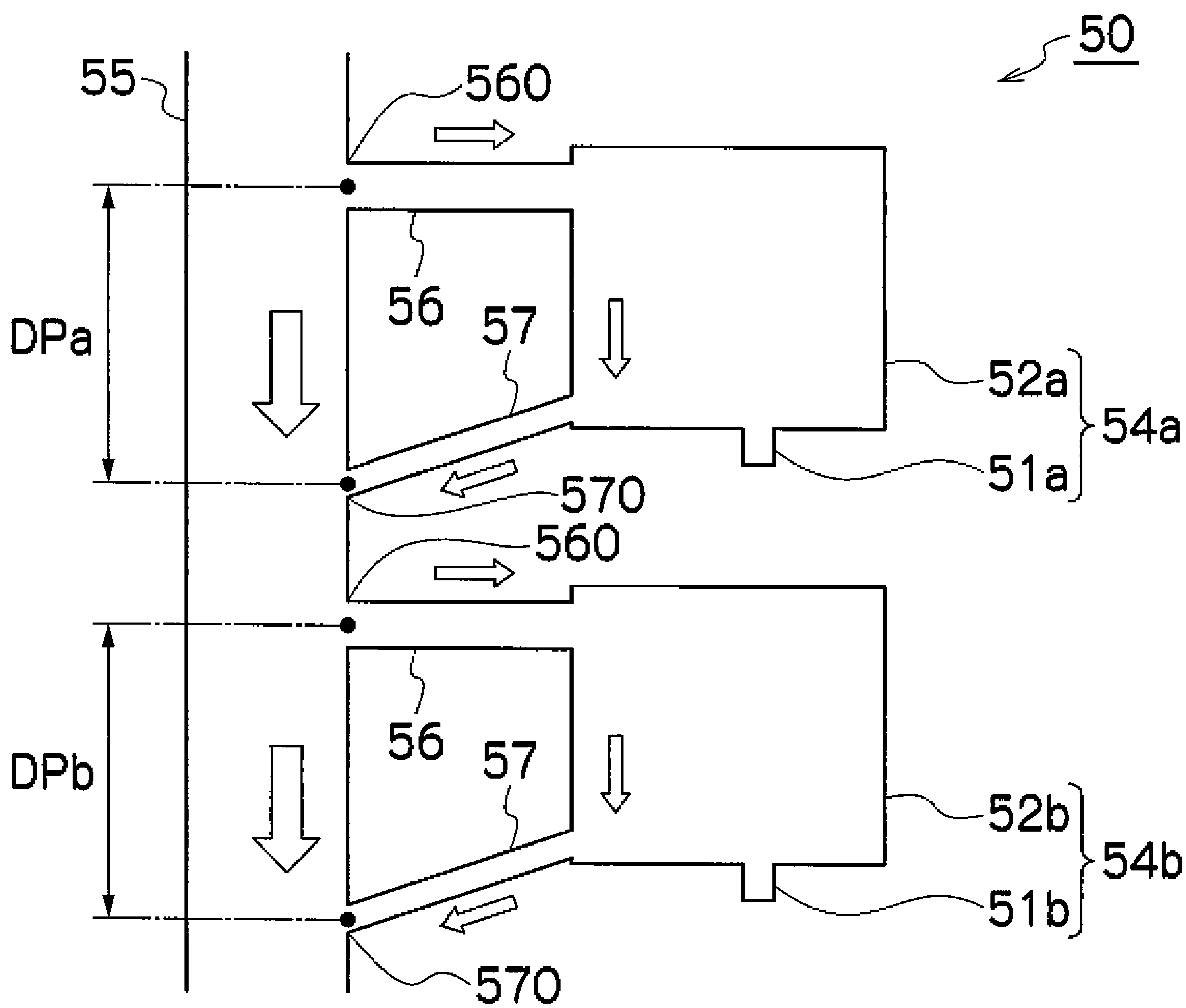


FIG.2

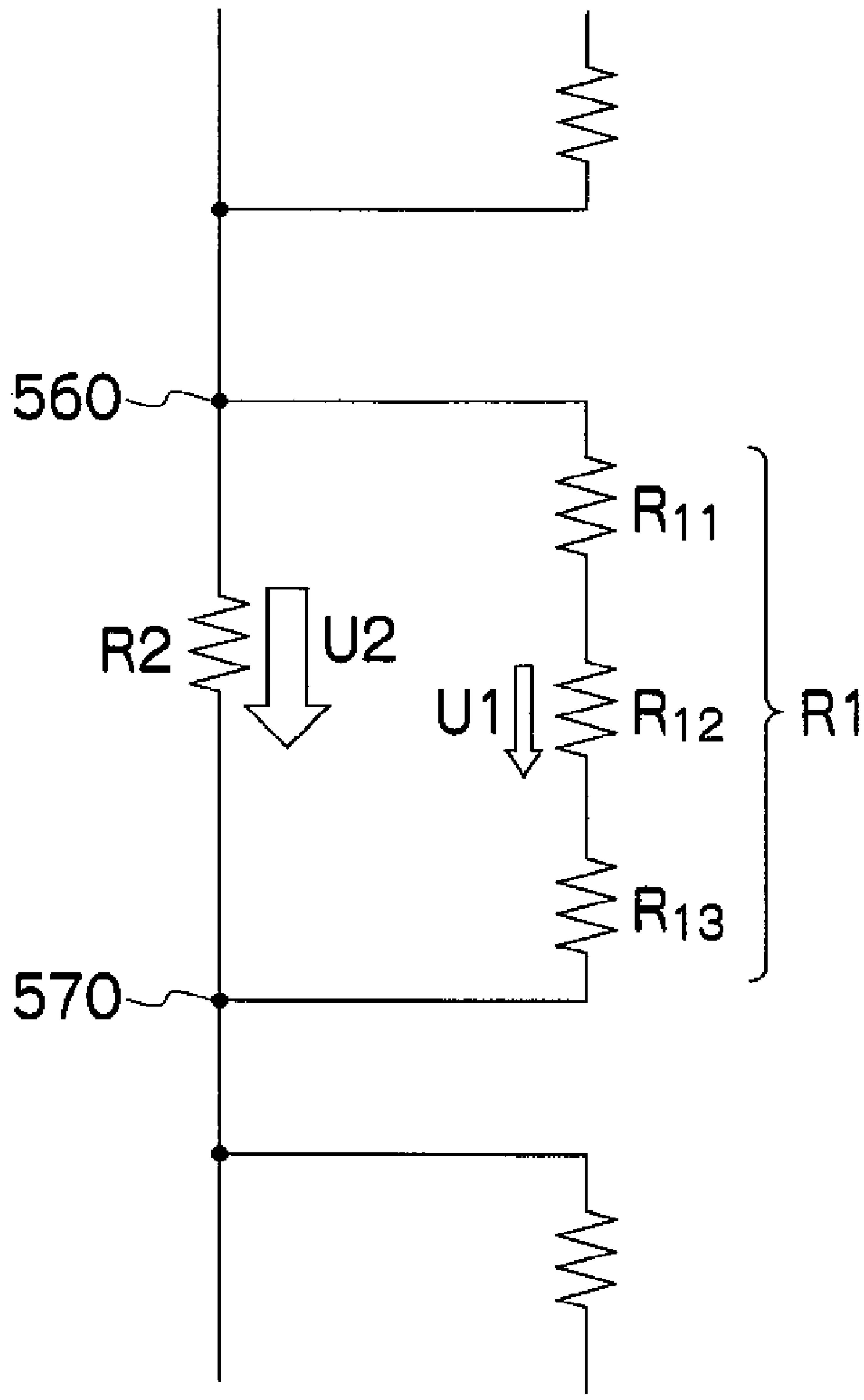


FIG.3

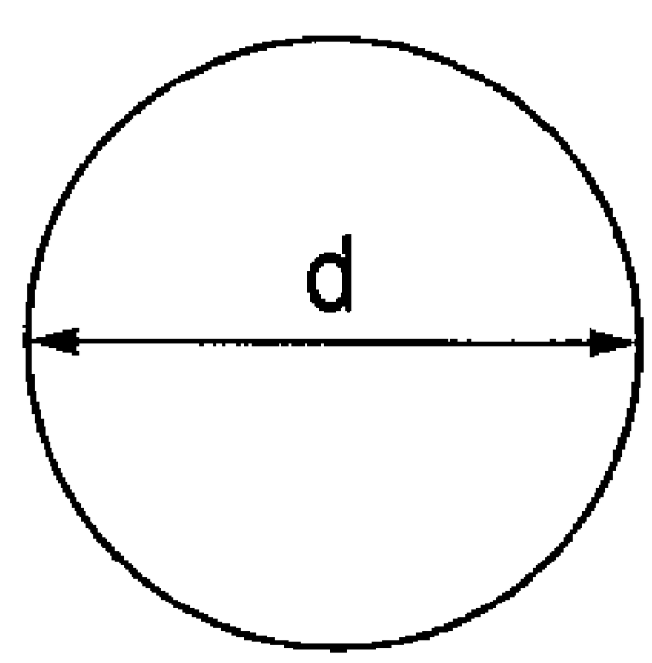


FIG.4

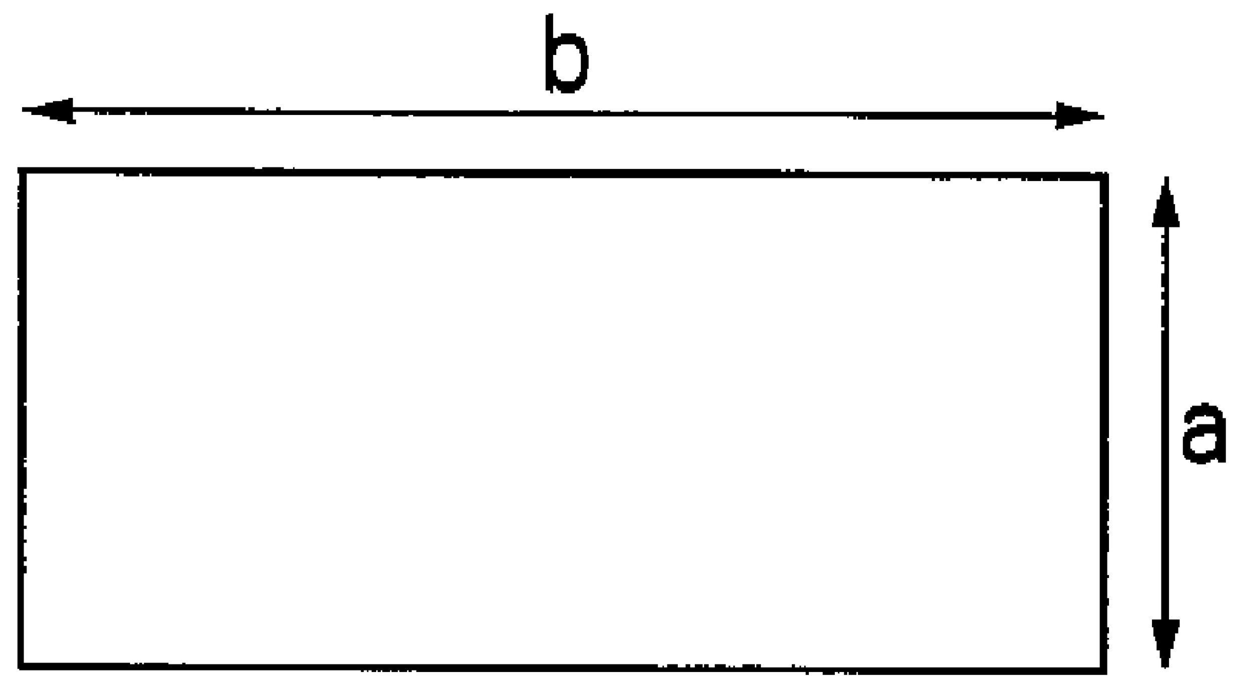

b
a

FIG.5

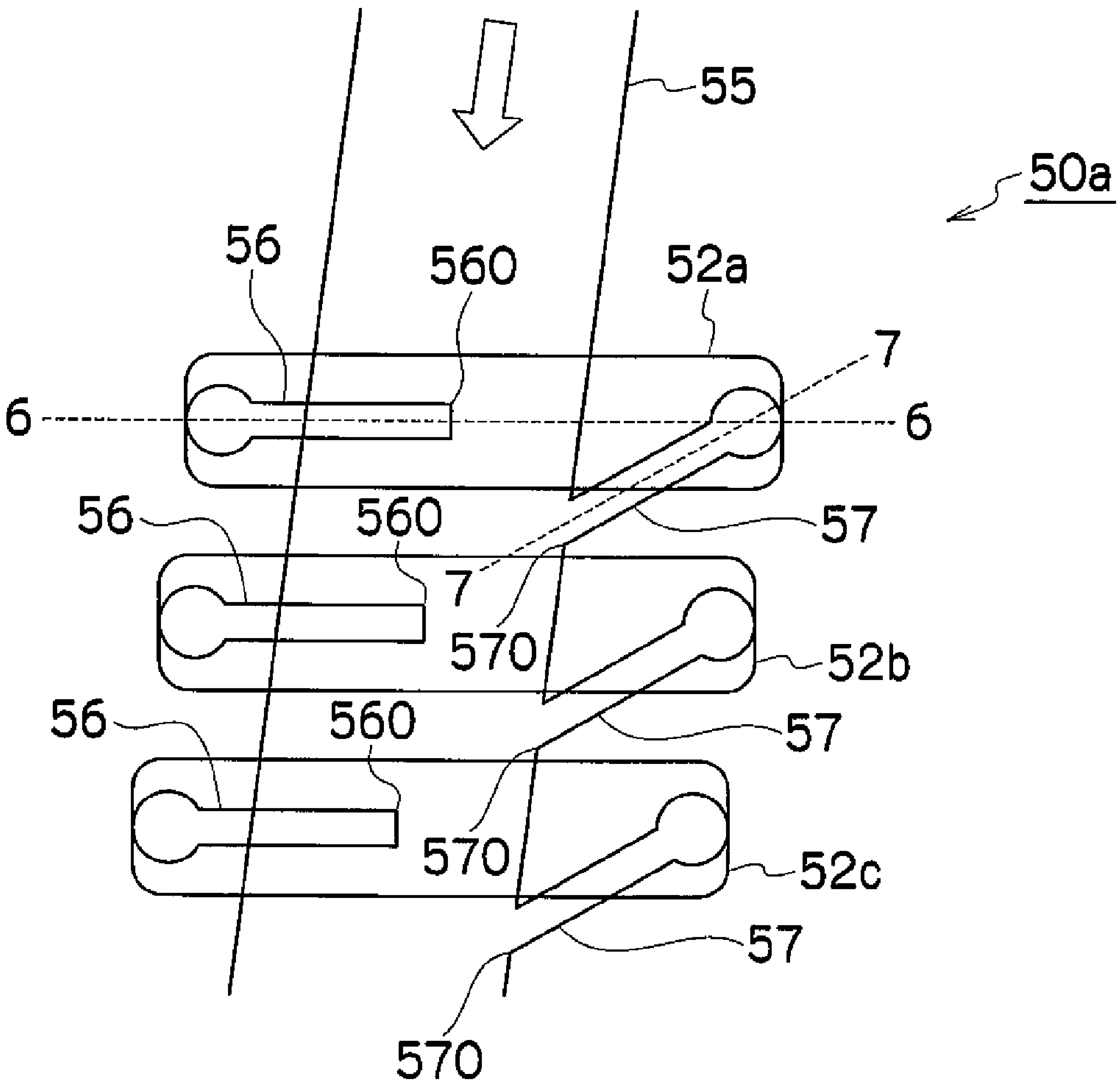

55
50a
56
560
52a
7
6
6
57
56
560
7
570
52b
57
56
560
570
52c
57
570

FIG.6

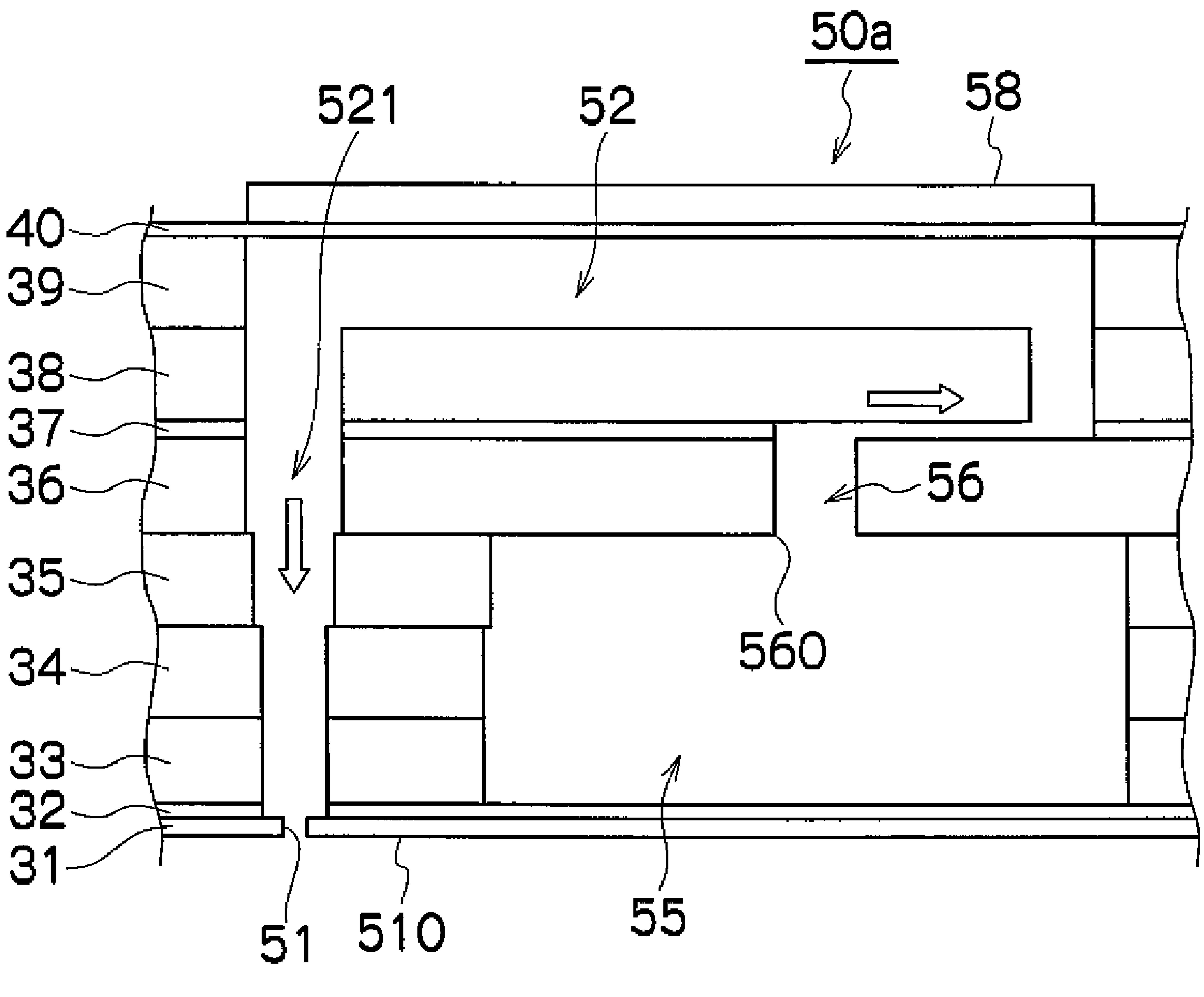


FIG.7

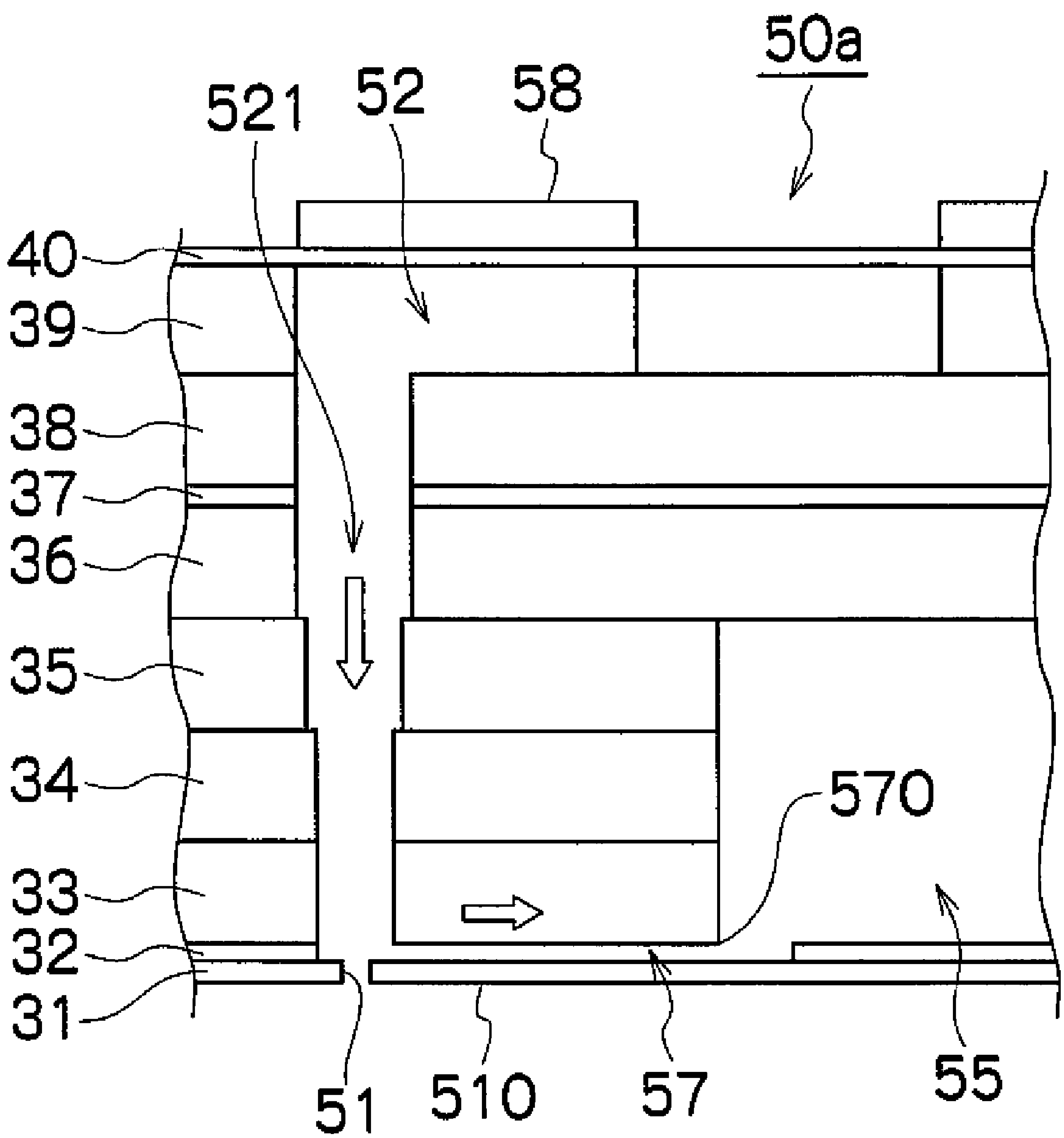


FIG.8

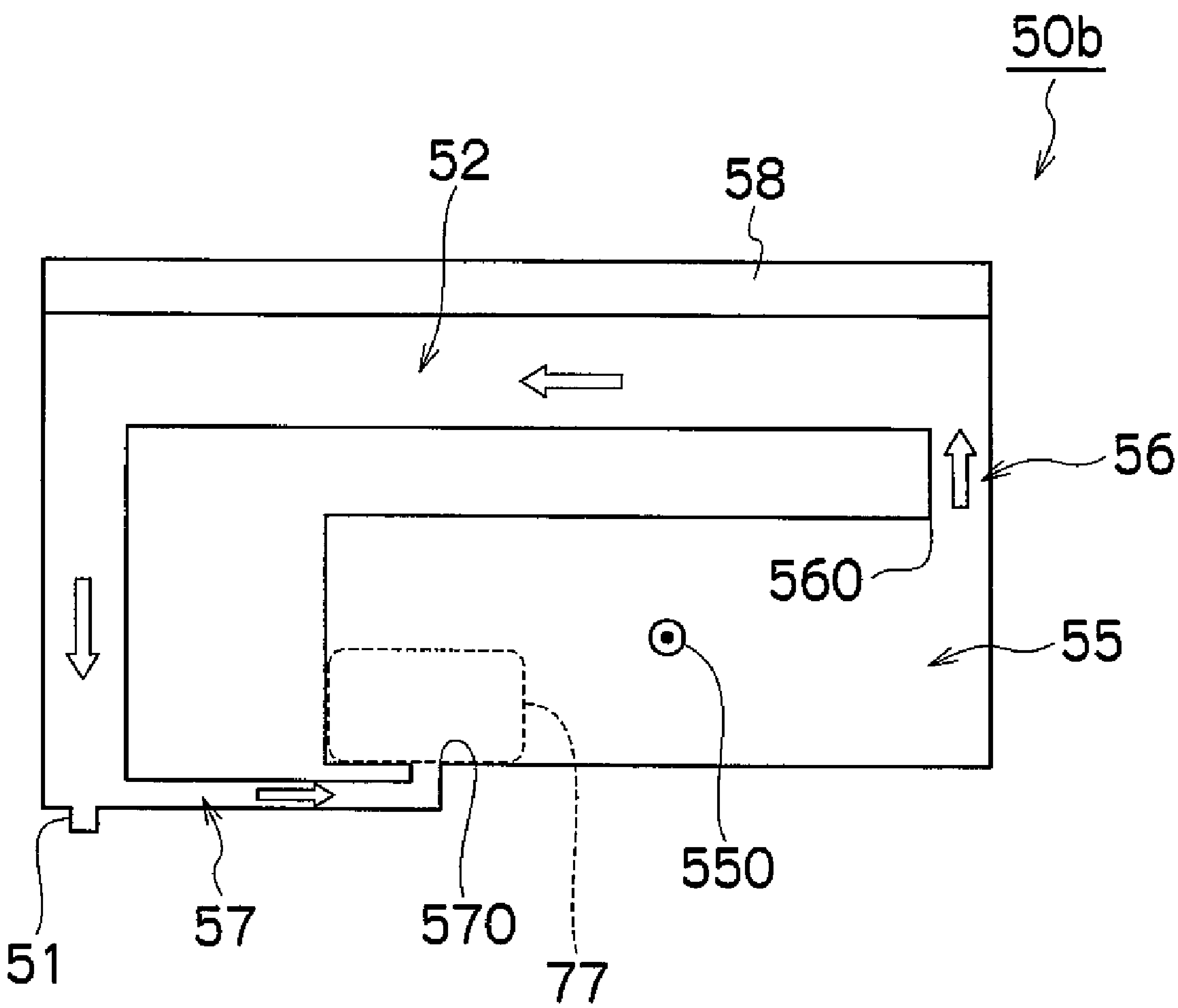
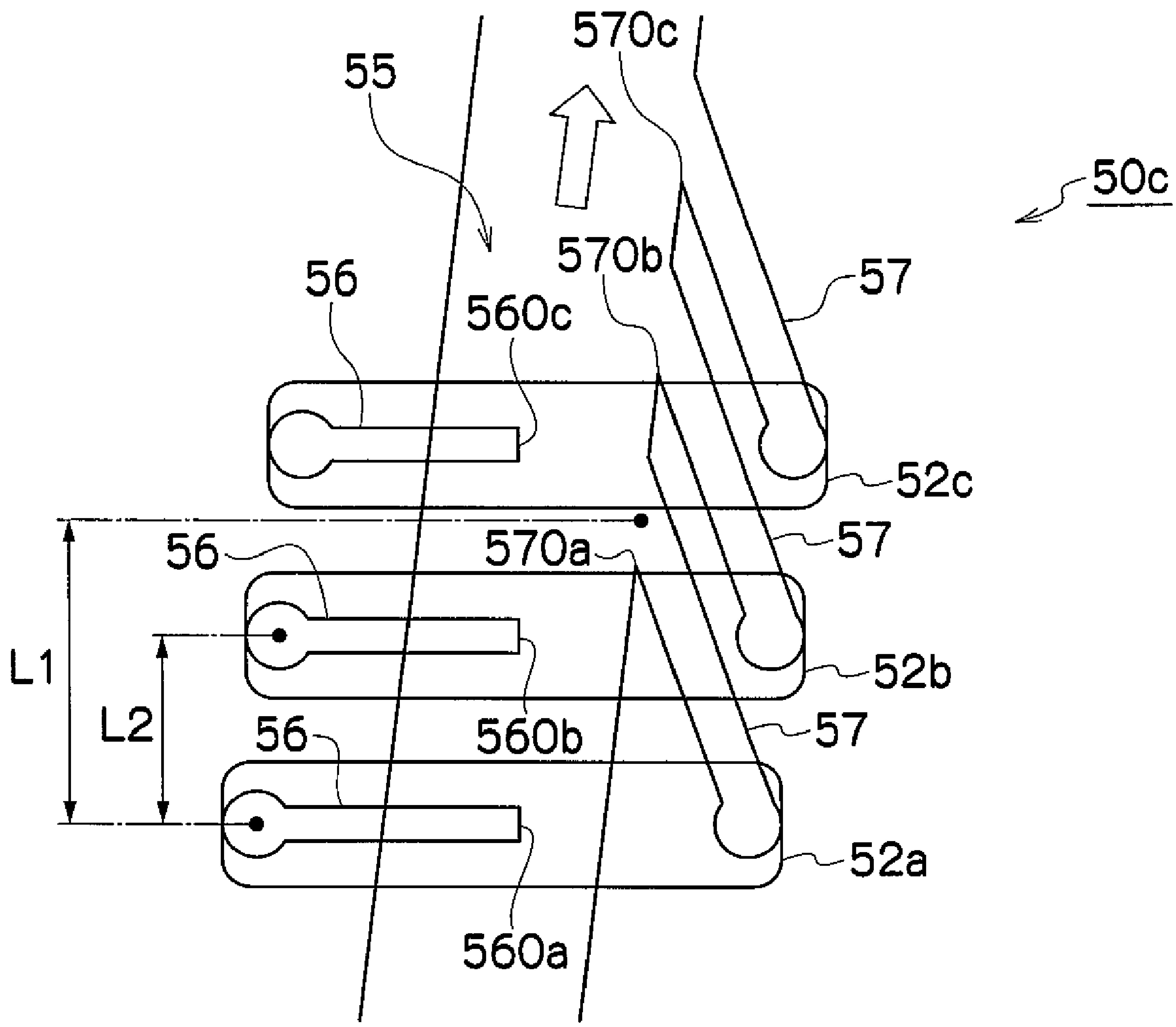


FIG.9



570c
55
50c
570b
57
56
560c
52c
57
56
570a
L1
52b
L2
56
560b
57
52a
560a

FIG.10

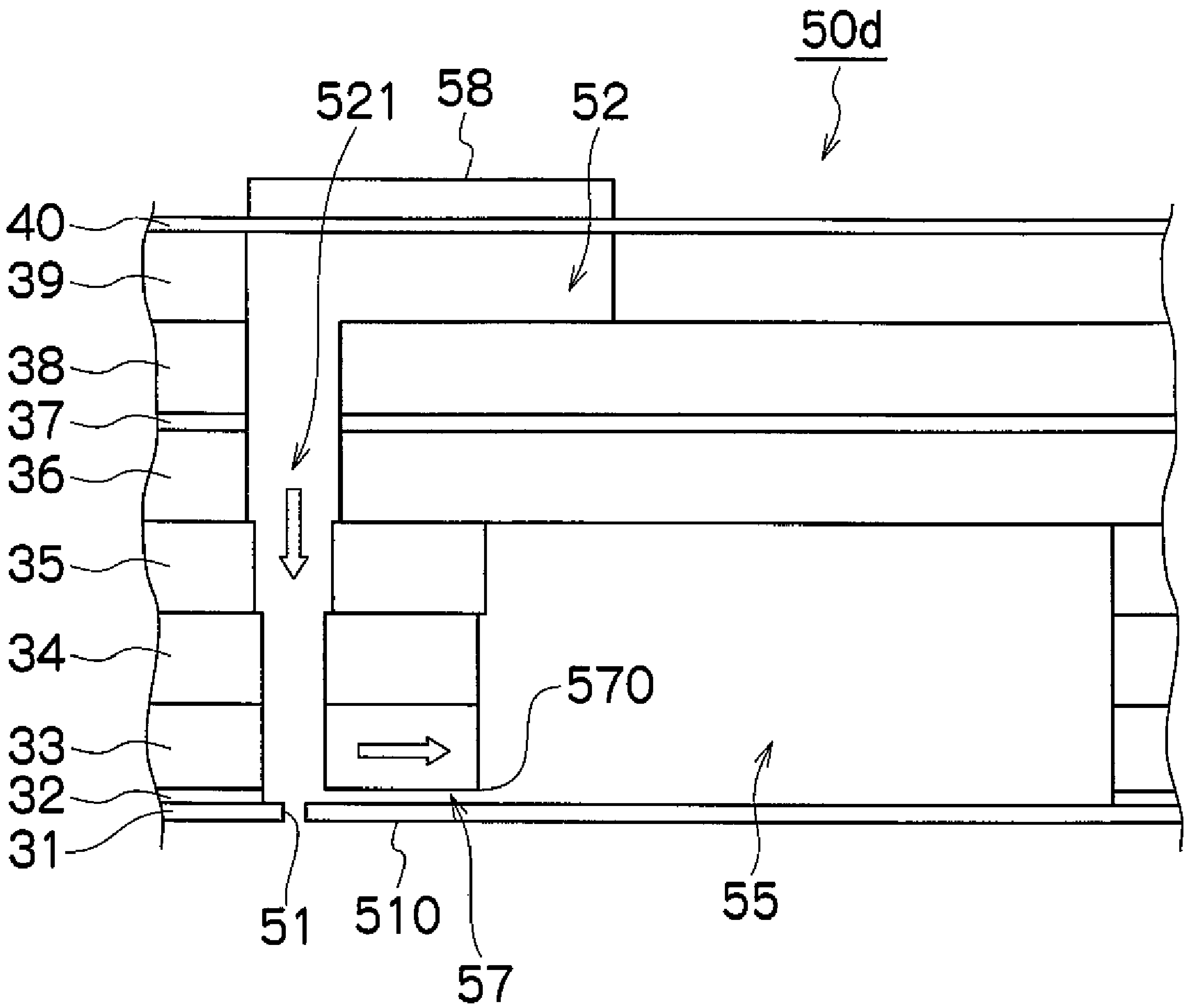


FIG.11

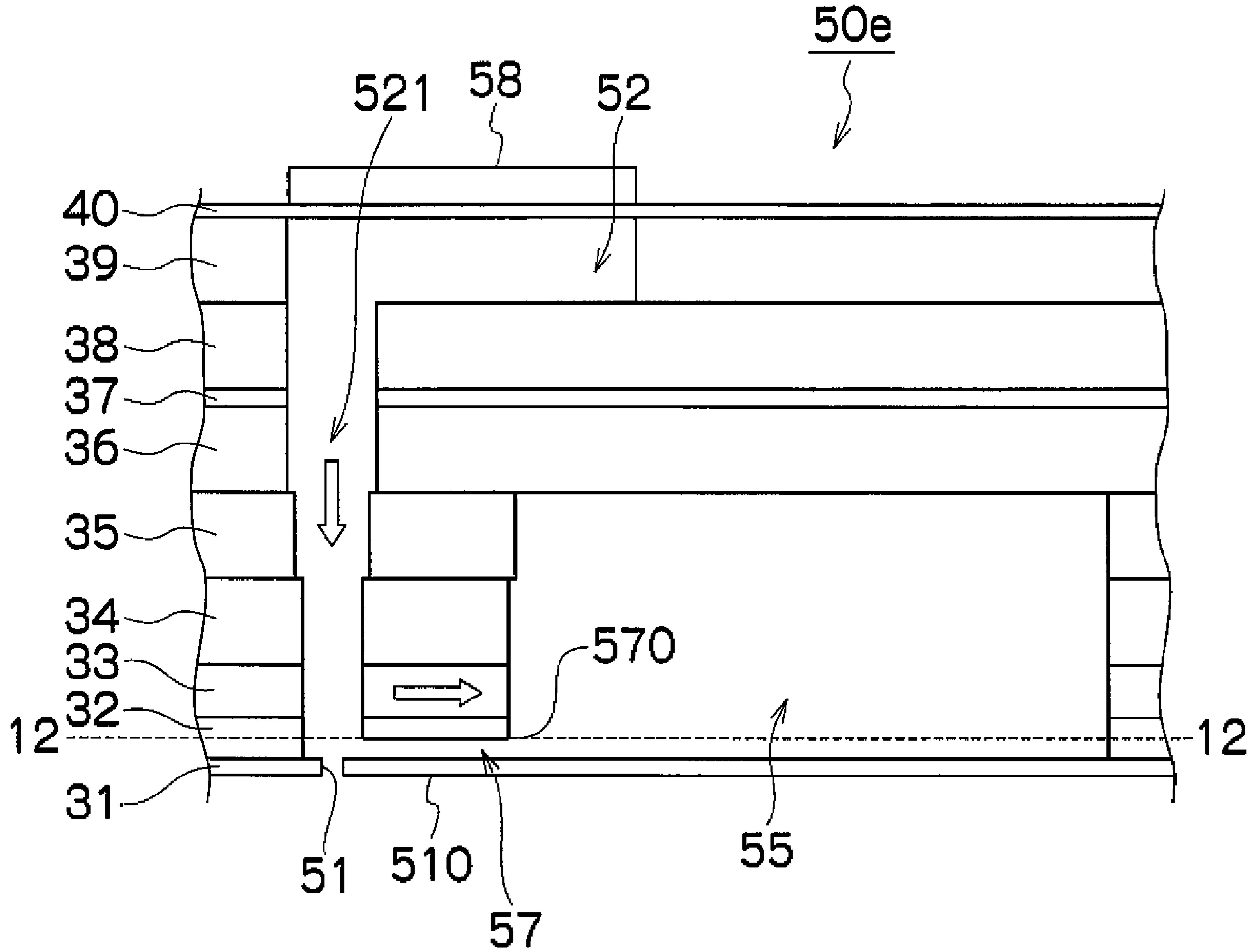


FIG.12

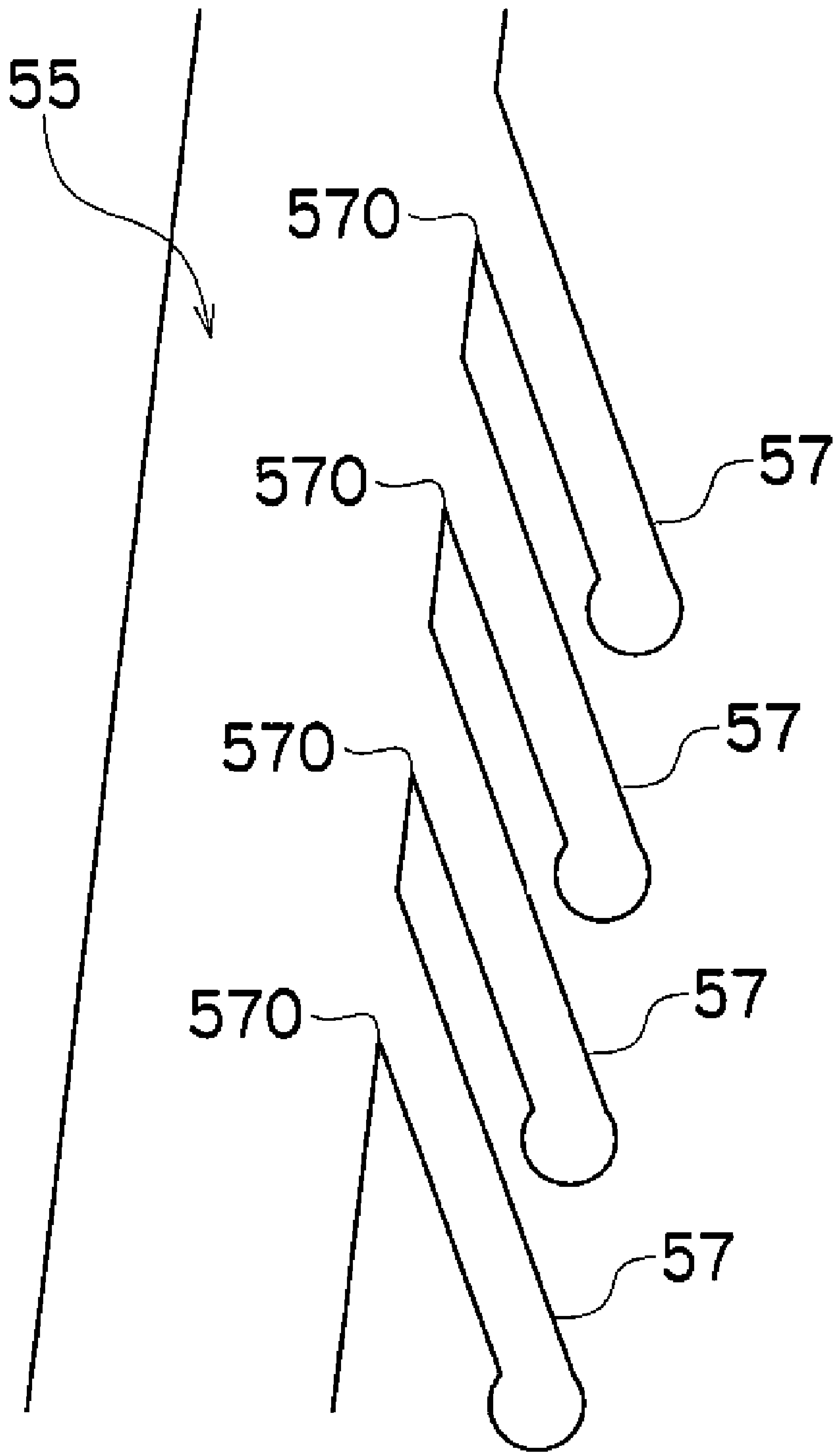


FIG.13

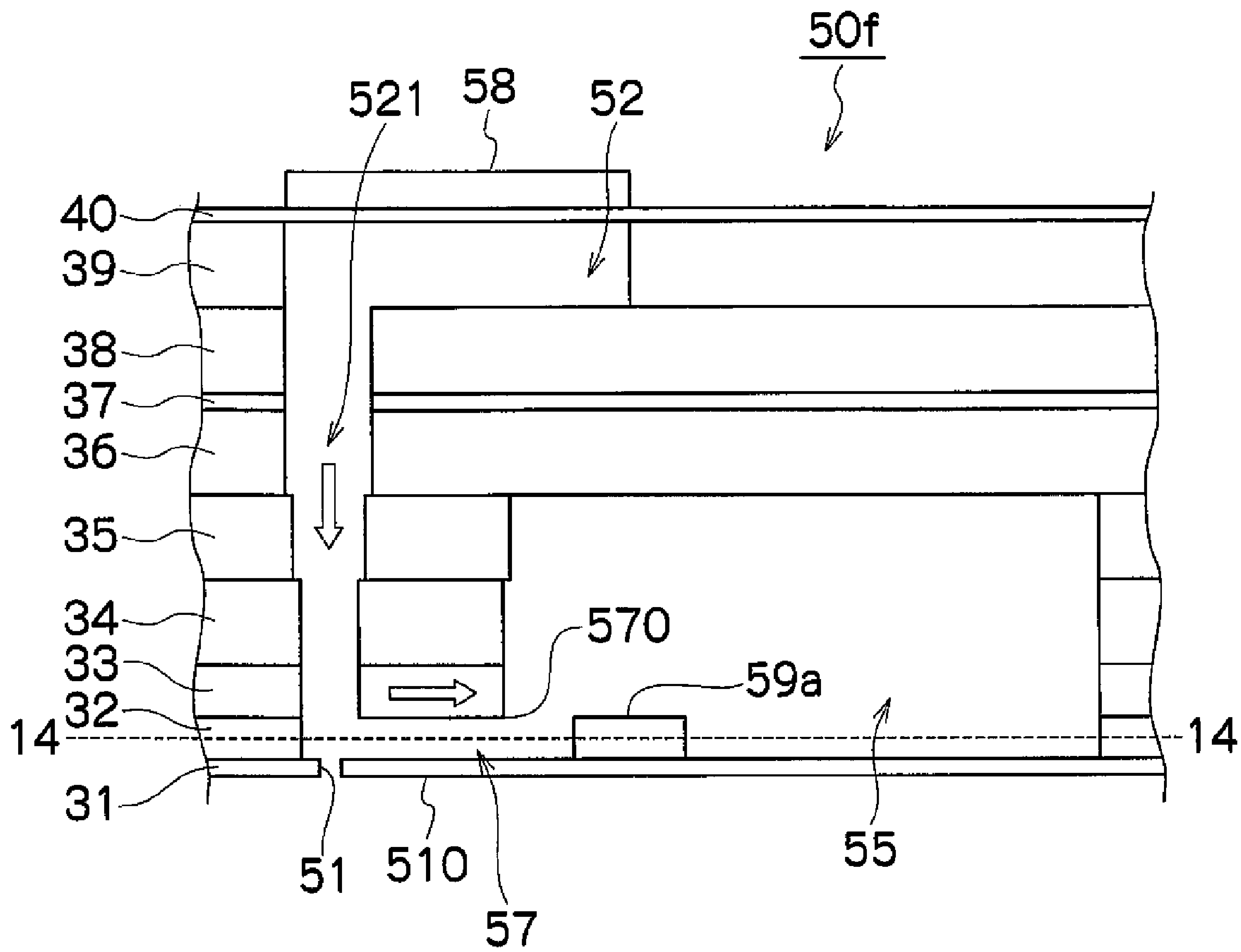


FIG.14

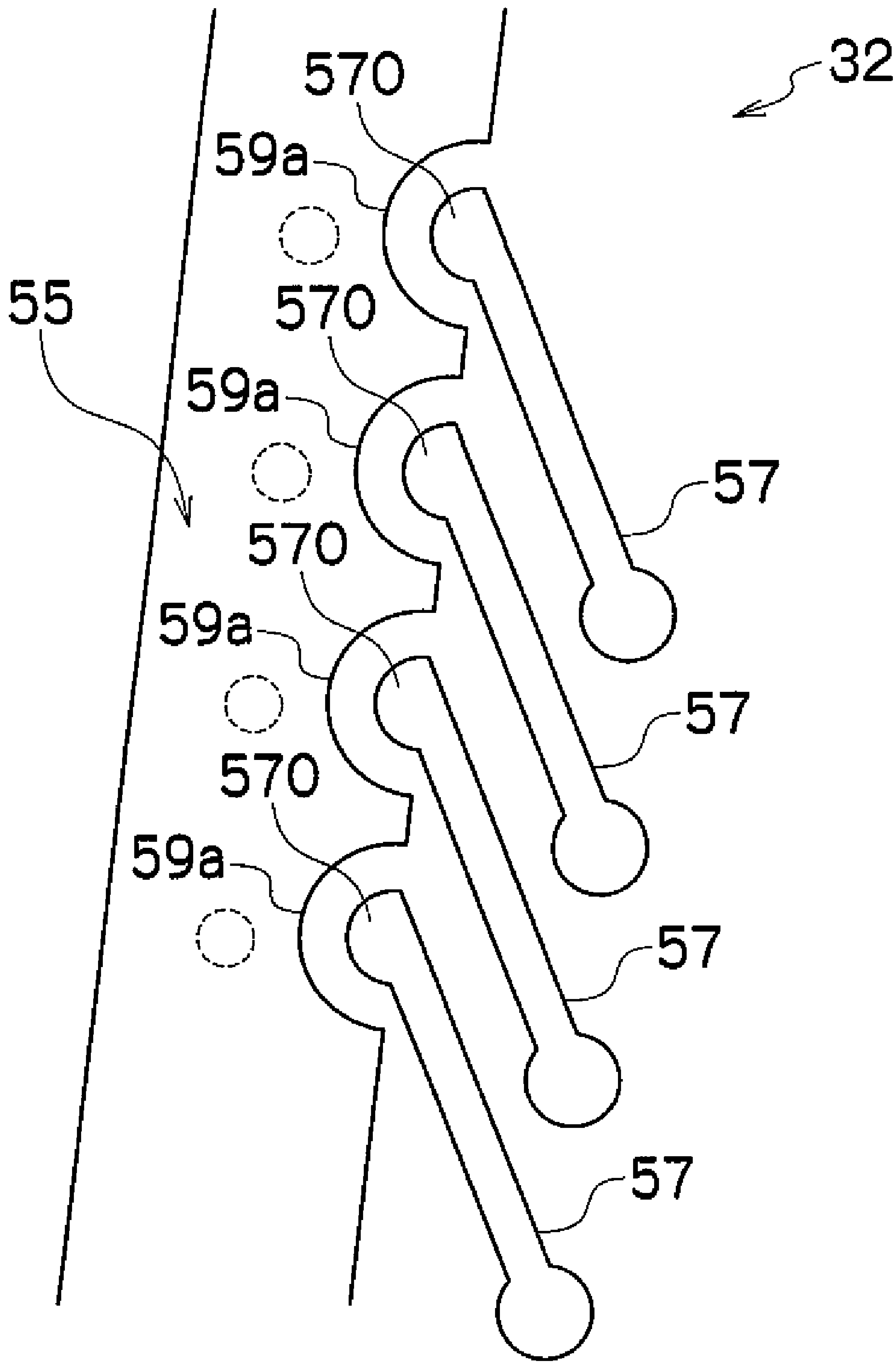


FIG.15

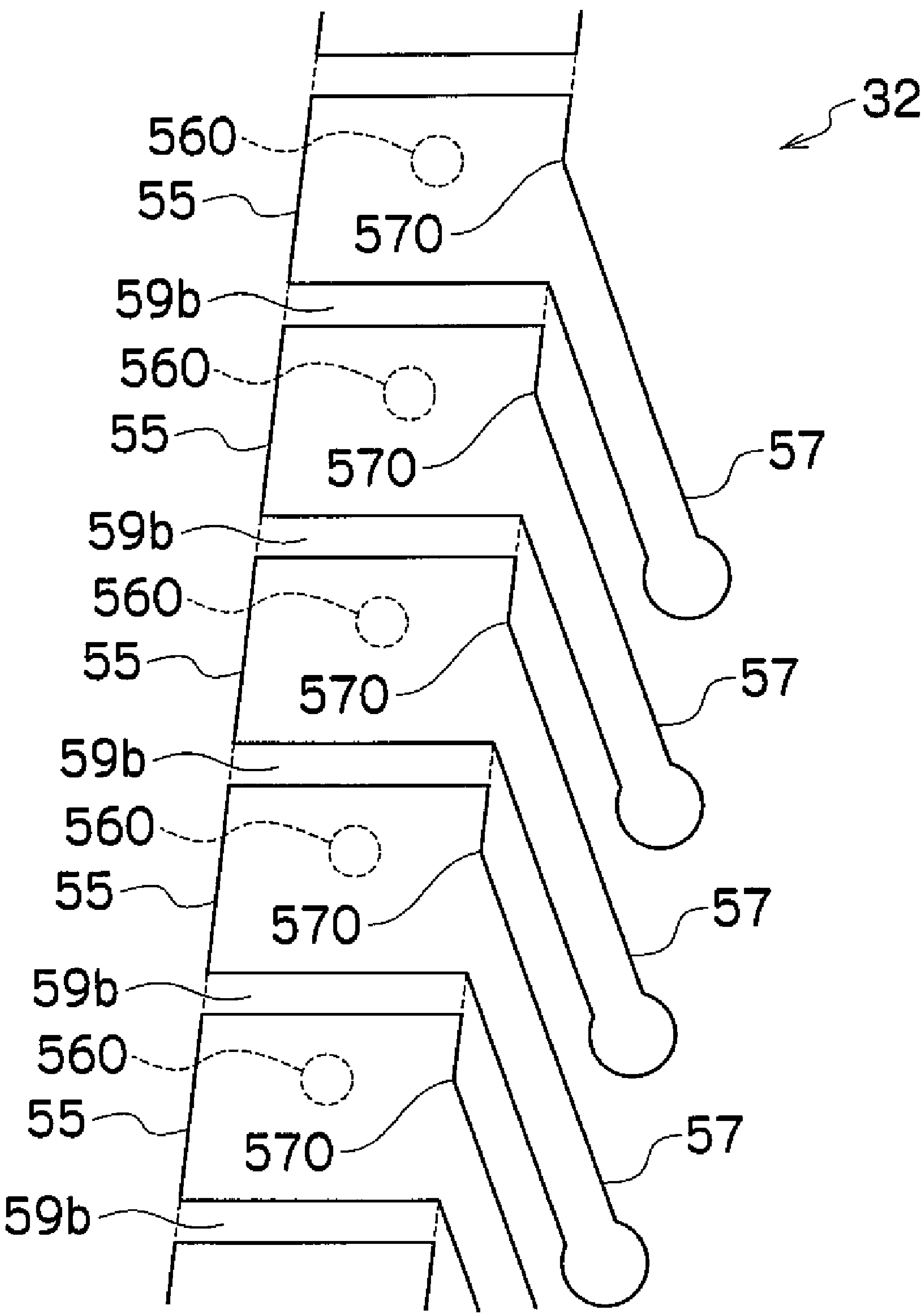

32
560
55
570
59b
560
55
570
57
59b
560
55
570
57
59b
560
55
570
57
59b
560
55
570
57
59b

FIG.16

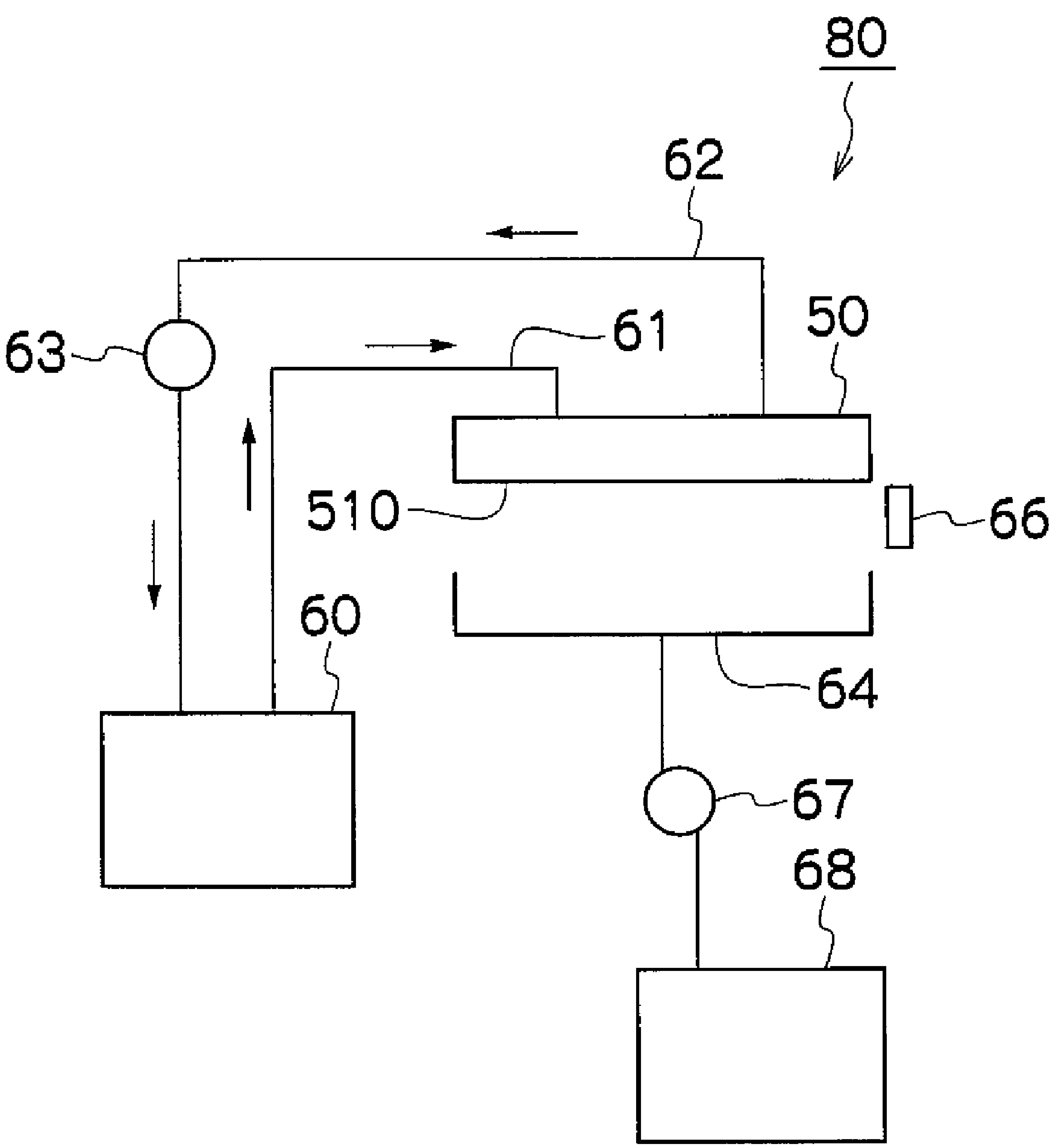


FIG.17

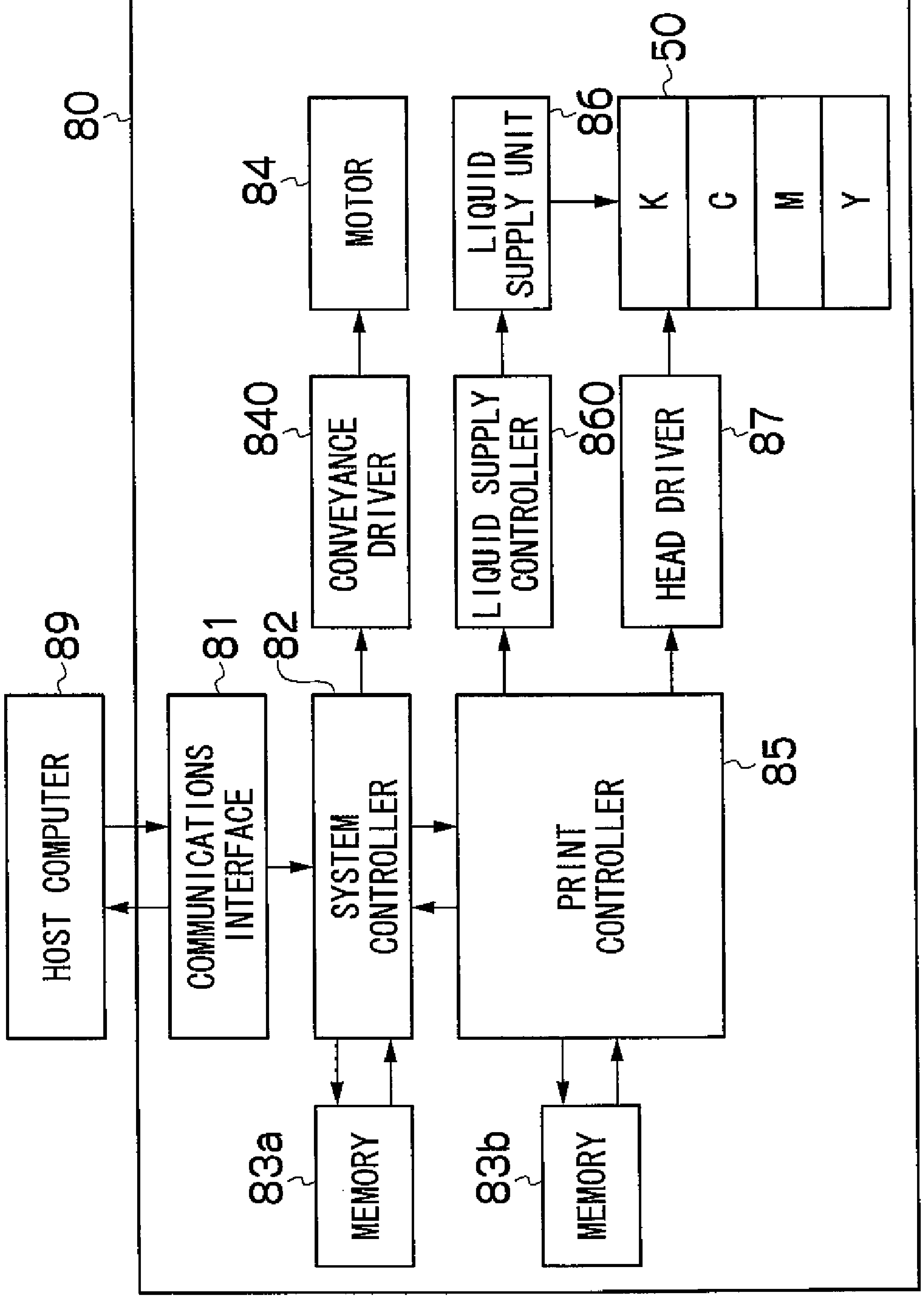

80
HOST COMPUTER
89
COMMUNICATIONS INTERFACE
81
SYSTEM CONTROLLER
82
PRINT CONTROLLER
85
MEMORY
83a
MEMORY
83b
CONVEYANCE DRIVER
840
LIQUID SUPPLY CONTROLLER
860
HEAD DRIVER
87
MOTOR
84
LIQUID SUPPLY UNIT
86
K
C
M
Y
50

FIG.18

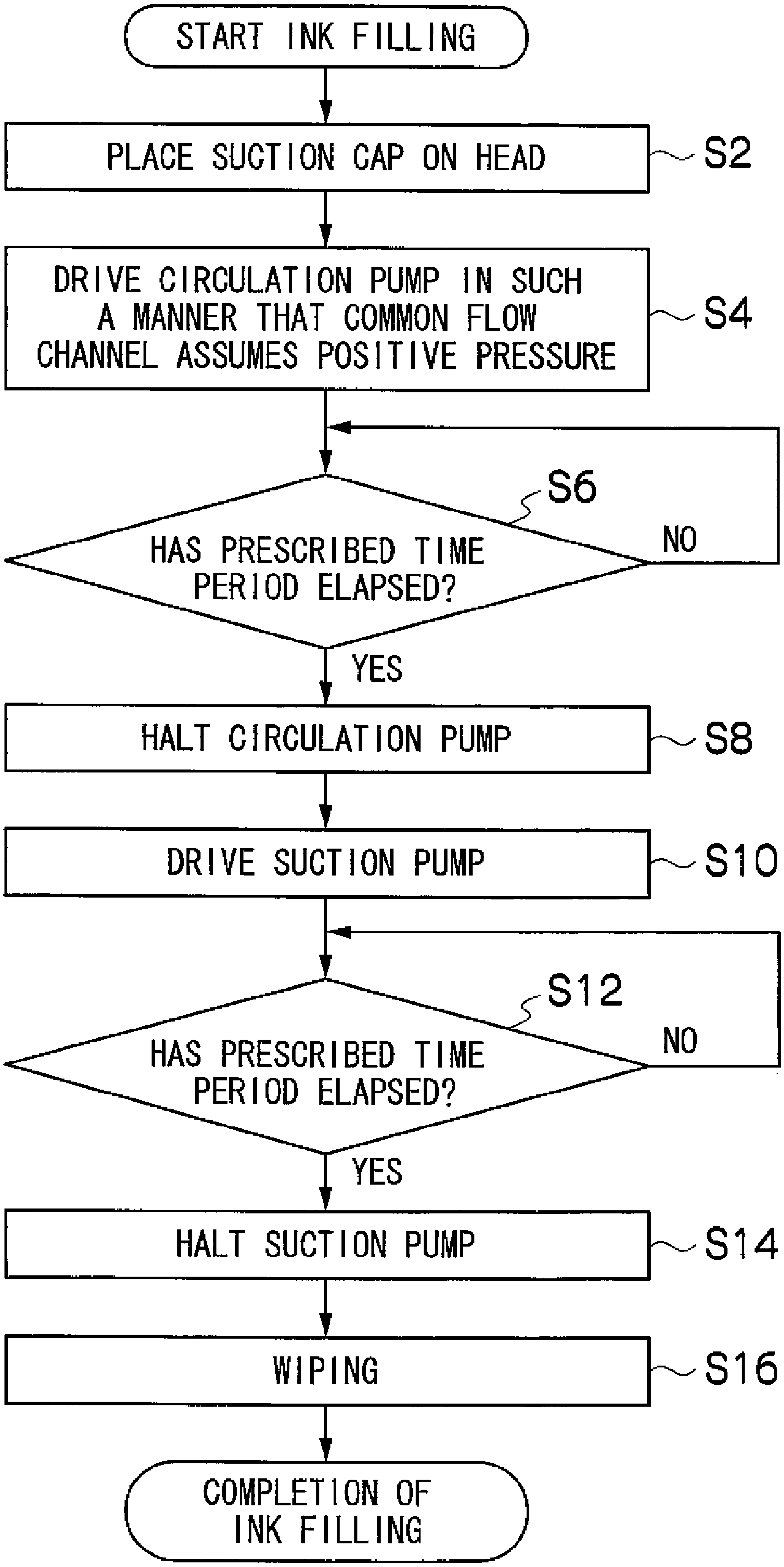

START INK FILLING
PLACE SUCTION CAP ON HEAD
S2
DRIVE CIRCULATION PUMP IN SUCH A MANNER THAT COMMON FLOW CHANNEL ASSUMES POSITIVE PRESSURE
S4
S6
HAS PRESCRIBED TIME PERIOD ELAPSED?
NO
YES
HALT CIRCULATION PUMP
S8
DRIVE SUCTION PUMP
S10
S12
HAS PRESCRIBED TIME PERIOD ELAPSED?
NO
YES
HALT SUCTION PUMP
S14
WIPING
S16
COMPLETION OF INK FILLING

FIG.19

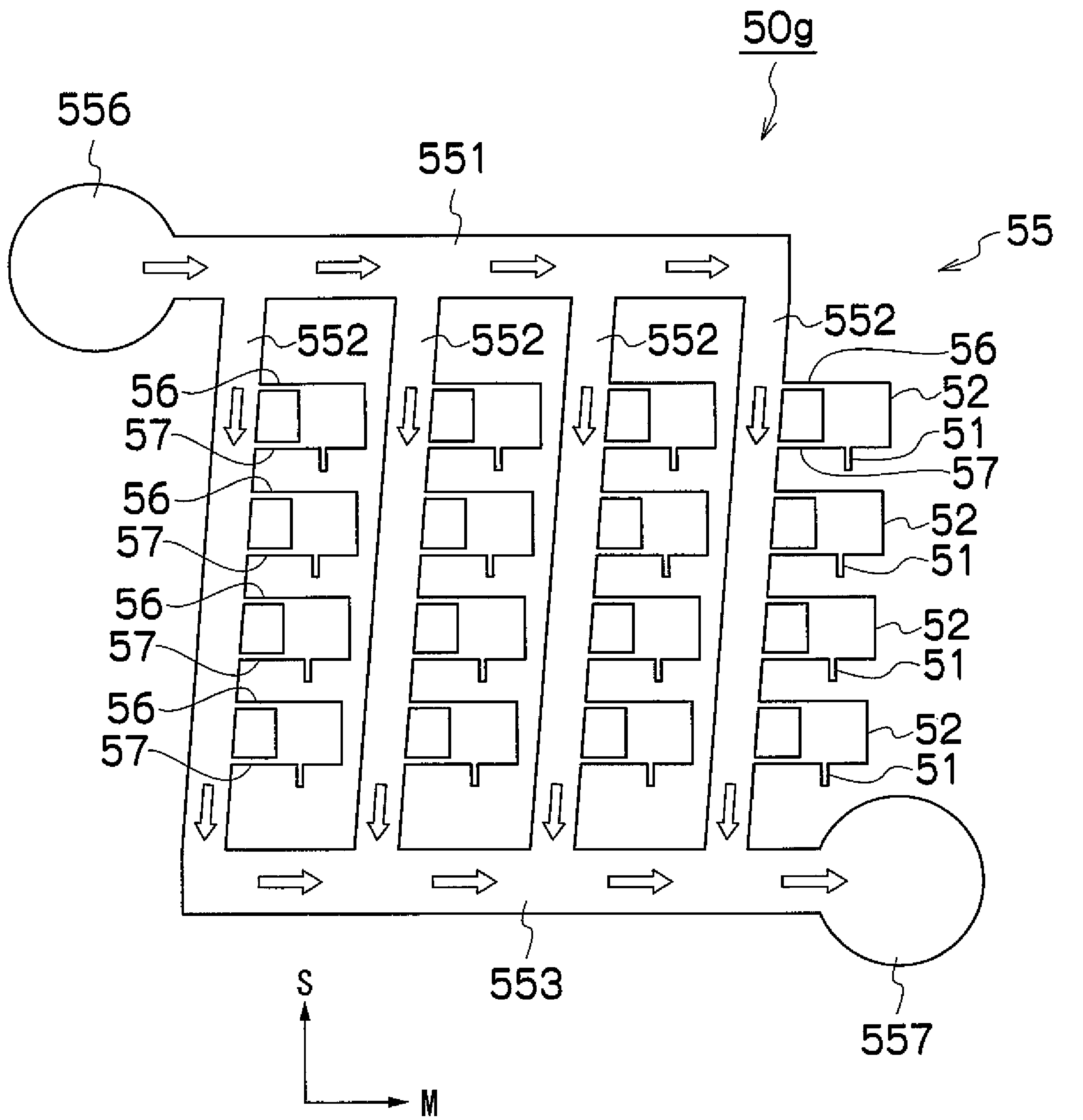
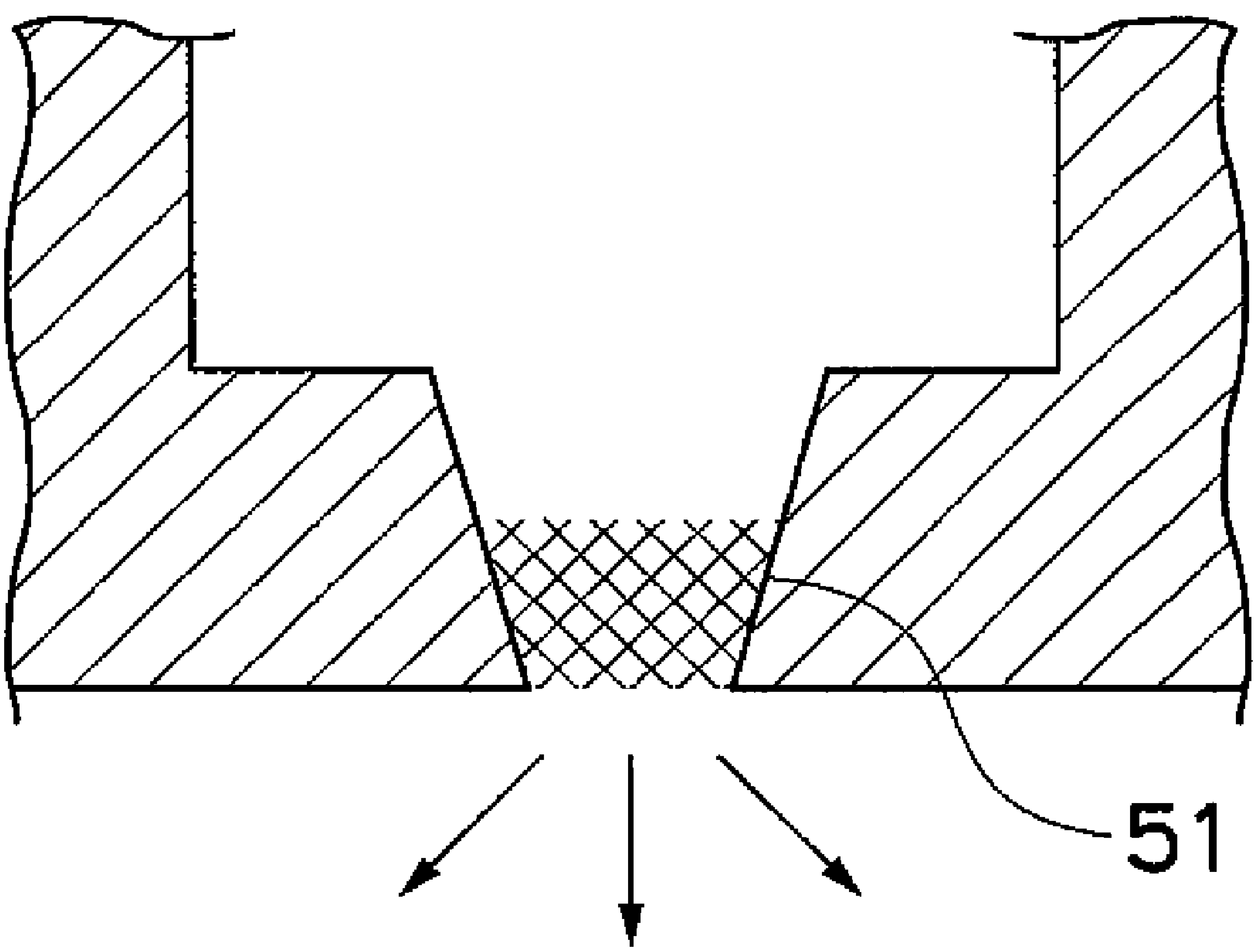

50g
556
551
55
552
552
552
552
56
52
51
57
56
57
56
57
56
57
56
57
52
51
52
51
52
51
553
557
S
M

FIG.20

RELATED ART



LIQUID EJECTION HEAD AND LIQUID EJECTION APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid ejection head and a liquid ejection apparatus each of which has nozzles from which liquid such as ink can be ejected.

2. Description of the Related Art

A liquid ejection head having an ink supply structure which is able to prevent increase in the viscosity of the ink inside the nozzles is desired.

Japanese Patent Application Publication No. 10-114081 discloses a liquid ejection head comprising: two common ink preparation chambers (common flow channels) which are connected respectively to either side of pressure generating chambers, via ink supply ports; and ink introduction ports via which ink is introduced into the respective ink preparation chambers from the exterior. Of the two ink introduction ports, one ink introduction port is connected to a sub tank, and the other ink introduction port is connected to an ink cartridge, and printing is carried out, while ink is replenished into the sub tank by making the ink pass from the ink cartridge through the liquid ejection head and the ink then flows in reverse by making the ink pass from the sub tank to the ink cartridge through the liquid ejection head.

As shown in FIG. **20**, the solvent in the ink evaporates from the meniscus of a nozzle **51** which is not ejecting ink, and hence there is a possibility that the viscosity of the ink increases. If the ink inside the nozzle **51** increases in viscosity, then the ejection speed declines and the image quality deteriorates. If the increase in viscosity increases further, then it becomes impossible to eject ink. If maintenance is carried out in order to remove the ink of increased viscosity by suction, it becomes possible to eject ink again, but in order to carry out maintenance of this kind, in general, it is necessary to halt printing, and therefore the apparatus operating time is reduced and printing costs increase.

Furthermore, in the apparatus described in Japanese Patent Application Publication No. 10-114081, if a pressure differential is applied between the two ink introduction ports which are provided in the ink preparation chamber (common flow chamber), then the flow rates of the ink flowing inside the respective pressure chambers differ. More specifically, a relatively large pressure differential is created on either side of a pressure chamber which is near to the ink introduction port, and a relatively small pressure differential is created on either side of a pressure chamber which is distant from the ink introduction port, and consequently, a relatively large amount of ink flows in a pressure chamber which is near to the ink introduction port, while a relatively small amount of ink flows in a pressure chamber which is distant from the ink introduction port.

If a difference arises in the ink flow rate between the pressure chambers, then not only is there a difference in the gas bubble expulsion properties between the pressure chambers, but furthermore, if the ink flows inside the pressure chamber during printing, then the effect of this ink flow on ejection will vary between the different pressure chambers, and therefore so-called “ejection variations” may arise.

Furthermore, in a liquid ejection head having a so-called matrix structure in which a plurality of nozzles are arranged at high density in order to achieve high image quality, it is difficult to increase the common flow channel in order to circulate the ink, for reasons of space.

SUMMARY OF THE INVENTION

The present invention has been contrived in view of these circumstances, an object thereof being to provide a liquid ejection head and a liquid ejection apparatus whereby increase in the viscosity of liquid in each nozzle can be prevented and ejection variations between nozzles can also be prevented.

One aspect of the present invention is directed to a liquid ejection head, comprising: a plurality of nozzles which eject liquid; a plurality of pressure chambers connected respectively to the plurality of nozzles; a common flow channel which is provided to be shared by the plurality of pressure chambers and has a plurality of supply flow channel connection ports and a plurality of circulation flow channel ports; a plurality of supply flow channels through which the liquid flows from the common flow channel to the plurality of pressure chambers via the plurality of supply flow channel connection ports; and a plurality of circulation flow channels through which the liquid flow from the plurality of pressure chambers to the common flow channel via the plurality of circulation flow channel ports, wherein the plurality of supply flow channel connection ports and the plurality of circulation flow channel ports are arranged so that a pressure differential of the liquid between the supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber is equal in respect of all of the plurality of pressure chambers.

In this aspect of the invention, the supply flow channel connection ports and the circulation flow channel connection ports which are opened in the common flow channel are disposed in positions whereby the pressure differential in the liquid between supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber is equal for all of the pressure chambers, and therefore it is possible to make the flow of liquid flowing in the pressure chamber equal in respect of all of the pressure chambers. Consequently, it is possible to make the effects of preventing increase in the viscosity of liquid and expelling gas bubbles equally in all of the pressure chambers, and therefore ejection variations between the nozzles can be prevented.

Desirably, a distance, in a direction of flow of the liquid in the common flow channel, between the supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber, is equal in respect of all of the plurality of pressure chambers.

In this aspect of the invention, since the pressure differential in the liquid between the supply flow channel connection port and the circulation flow channel connection port which are connected to the same pressure chamber can readily be made equal in respect of all of the pressure chambers, then it is possible readily to make the flow of liquid flowing inside the pressure chamber equal in all of the pressure chambers. Consequently, it is possible readily to make the effects of preventing increase in the viscosity of liquid and expelling gas bubbles equally in all of the pressure chambers, and therefore ejection variations between the nozzles can be prevented.

Desirably, taking the distance between the supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber to be L**1**, and taking a distance between the supply flow channel connection ports which are mutually adjacent and are connected respectively to the different pressure chambers, to be L**2**, then L**1**>L**2** is satisfied.

In this aspect of the invention, it is possible to make the pressure differential (the back pressure differential) between the pressure chambers small, while maintaining a large volume of liquid flowing in the pressure chambers. It is also possible to increase the effects of preventing increase in the viscosity of liquid and the effects of expelling gas bubbles, while ensuring little ejection variation between the nozzles.

Desirably, the plurality of circulation flow channels are connected to lower portions of the common flow channel in terms of a vertical direction.

In this aspect of the invention, the gas bubbles in the common flow channel are not liable to enter into the nozzles and pressure chambers via the ink circulation flow channels, and therefore ejection abnormalities caused by the gas bubbles in the common flow channel are prevented.

Desirably, the plurality of supply flow channel connection ports and the plurality of circulation flow channel ports are arranged at substantially diagonally opposite positions of the common flow channel.

In this aspect of the invention, the liquid returning to the common flow channel via the ink circulation flow channels is prevented from being supplied directly to the pressure chambers via the ink supply flow channels, and therefore it is possible reliably to prevent increase in the viscosity of liquid.

Desirably, The liquid ejection head comprises a plurality of superimposed plates is including a nozzle plate in which the plurality of nozzles are formed and a circulation flow channel plate in which the plurality of circulation flow channels are formed, wherein the circulation flow channel plate is adjacent to the nozzle plate; and the common flow channel is formed in contact with the nozzle plate.

In this aspect of the invention, it is possible to make the liquid in the vicinity of the nozzle return to the common flow channel in order to maximize the effects in preventing increase in the viscosity of liquid, while also obtaining a damping capacity in the common flow channel with respect to cross talk between pressure chambers.

Desirably, a height of the plurality of circulation flow channels is smaller than a thickness of the circulation flow channel plate.

Here, the ink circulation flow channels may be formed by half etching the circulation flow channel plate, for example.

In this aspect of the invention, it is possible to increase the rigidity of the circulation flow channel forming plate and to preserve the shape of the circulation flow channels. Furthermore, since the flow channel resistance of the ink circulation flow channels is increased, then it is also possible to increase the ejection efficiency.

Desirably, the plurality of circulation flow channels are formed on a side adjacent to the nozzle plate, in terms of a thickness direction of the circulation flow channel plate.

In this aspect of the invention, not only does it become possible to improve the rigidity of the circulation flow channel forming plate and to preserve the shape of the circulation flow channels, but also the liquid in the vicinity of the nozzles can be circulated to the common flow channel, and therefore a beneficial effect in preventing increase in viscosity can be expected.

Desirably, rigid bodies are disposed in the common flow channel so as to surround the plurality of circulation flow channel connection ports.

In this aspect of the invention, it is possible to increase the rigidity of the circulation flow channel forming plate and to preserve the shape of the ink circulation flow channels, without using half etching.

Desirably, rigid bodies are disposed in the common flow channel, and each of the rigid bodies is arranged between the supply flow channel connection ports which are mutually adjacent.

In this aspect of the invention, it is possible to prevent the cross-talk waves which exit from the ink supply flow channel connection ports (ink supply ports), from striking directly against the rigid bodies, and therefore a damping effect with respect to cross-talk between the pressure chambers is obtained and the ejection stability is improved.

Another aspect of the present invention is directed to a liquid ejection apparatus comprising any one of the above-mentioned liquid ejection heads.

Desirably, the liquid ejection apparatus further comprises a liquid flow creating device which creates a flow of the liquid in the common flow channel while the liquid ejection head performs ejection of the liquid.

For example, the liquid flow creating device may be constituted by a pump which is provided in a tubular channel which is connected to the liquid ejection head.

In this aspect of the invention, an effect in supplementing the refilling of liquid into the pressure chambers is obtained.

According to the present invention, it is possible to prevent increase in the viscosity of liquid in the nozzles, while also being able to prevent ejection variations between the nozzles.

BRIEF DESCRIPTION OF THE DRAWINGS

The nature of this invention, as well as other objects and benefits thereof, will be explained in the following with reference to the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures and wherein:

FIG. **1** is a perspective diagram showing the composition of a liquid ejection head relating to an embodiment of the present invention;

FIG. **2** is a diagram showing an equivalent model which is equivalent to the principal part of the liquid ejection head in FIG. **1**;

FIG. **3** is a cross-sectional diagram of a circular tube;

FIG. **4** is a cross-sectional diagram of a flow channel having a rectangular shaped cross-section;

FIG. **5** is a plan view perspective diagram showing the principal part of a liquid ejection head which is one example of a first embodiment of the present invention;

FIG. **6** is a vertical cross-sectional diagram along line **6-6** in FIG. **5**;

FIG. **7** is a vertical cross-sectional diagram along line **7-7** in FIG. **5**;

FIG. **8** is a vertical cross-sectional perspective diagram showing the principal part of a liquid ejection head which is a further example of the first embodiment;

FIG. **9** is a plan view perspective diagram showing the principal part of a liquid ejection head which is one example of a second embodiment of the invention;

FIG. **10** is a plan view perspective diagram showing the principal part of a liquid ejection head which is one example of a third embodiment;

FIG. **11** is a plan view perspective diagram showing the principal part of a liquid ejection head which is one example of a fourth embodiment;

FIG. **12** is a horizontal cross-sectional diagram along line **12-12** in FIG. **11**;

FIG. **13** is a plan view perspective diagram showing the principal part of a liquid ejection head which is one example of a fifth embodiment;

FIG. **14** is a horizontal cross-sectional diagram along line **14-14** in FIG. **13**;

FIG. **15** is a horizontal cross-sectional diagram used to describe a further example of rigid bodies;

FIG. **16** is a schematic drawing showing the composition of a liquid supply system and a maintenance system of an image forming apparatus which is one example of a liquid ejection apparatus;

FIG. **17** is a block diagram showing the composition of the control system of an image forming apparatus which is one example of a liquid ejection apparatus;

FIG. **18** is a general flowchart showing the sequence of an ink refilling process;

FIG. **19** is a perspective diagram showing the composition of a liquid ejection head having a matrix structure; and

FIG. **20** is an illustrative diagram used to describe increase in the viscosity of ink caused by evaporation of solvent from the nozzles.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Liquid Ejection Head

FIG. **1** is basic schematic drawing showing the basic composition of the principal part of a liquid ejection head relating to an embodiment of the present invention.

In FIG. **1**, the liquid ejection head **50** comprises a plurality of nozzles **51** which eject ink (e.g. a first nozzle **51***a* and a second nozzle **51***b*), and a plurality of pressure chambers **52** which are connected respectively to these nozzles **51** (e.g. a first pressure chamber **52***a* and a second pressure chamber **52***b*). In other words, the liquid ejection head **50** comprises a plurality of ejectors **54** arranged suitably (e.g. a first ejector **54***a* and a second ejector **54***b*) each comprising a nozzle **51** and a pressure chamber **52** connected to the nozzle **51**. FIG. **1** shows only two ejectors **54** in order to simplify the illustration, but there is no particular restriction on the number of ejectors **54**. In other words, there is no particular restriction on the number of nozzles **51** and pressure chambers **52**.

The common liquid chamber **55** is a flow channel which is provided commonly for a plurality of pressure chambers **52**, and which supplies ink to the plurality of pressure chambers **52**. The common flow channel **55** is disposed following an arrangement direction in which the pressure chambers **52** are aligned. In other words, a plurality of pressure chambers **52** are arranged following the direction of the flow of liquid in the common flow channel **55**.

For each of the plurality of pressure chambers **52**, an ink supply flow channel **56** which supplies ink from the common flow channel **55** to the pressure chamber **52**, and an ink circulation flow channel **57** which returns ink from the pressure chamber **52** to the common flow channel **55**, are formed between the pressure chamber **52** and the common flow channel **55**. Below, connection ports **560** opened in the common flow channel **55** where they are connected with the ink supply flow channels **56** respectively are also called "ink supply ports" and connection ports **570** which are connected with the ink circulation flow channels **57** respectively are also called "ink circulation ports".

Looking specifically at the ink supply port **560** and the ink circulation port **570** which are connected to the same pressure chamber **52**, the ink supply port **560** is disposed to the upstream side of the ink circulation port **570** in terms of the flow direction of the liquid in the common flow channel **55**.

The cross-sectional area of the common flow channel **55** (the surface area of the cross-section perpendicular to the direction of flow of the liquid in the common flow channel **55**) is the same for all of the pressure chambers **52**, through the liquid flow direction, and the distance DPa between the ink supply port **560** and the ink circulation port **570** which are connected to a first pressure chamber **52***a* is equal to the distance DPb between the ink supply port **560** and the ink circulation port **570** which are connected to a second pressure chamber **52***b*. This relationship is established with respect to all the pressure chambers **52** in the liquid ejection head **50**. In other words, in respect of all of the pressure chambers **52**, the distances each of which follows the flow direction of the liquid in the common flow channel **55** between an ink supply port **560** and an ink circulation port **570** which are opened in the common flow channel **55** and which connect to the same pressure chamber **52**, are the same distance. Here, the magnitude of the distance between the ink supply port **560** and the ink circulation port **570** corresponds to the magnitude of the pressure differential in the liquid between the ink supply port **560** and the ink circulation port **570**. In the present embodiment, the ink supply ports **560** and the ink circulation ports **570** which are opened in the common flow channel **55** are arranged at positions so that the pressure differential in the ink between the ink supply port **560** and the ink circulation port **570** which are connected to the same pressure chamber **52** is equal, at all of the pressure chambers **52**. Therefore, the flow rates of the ink flowing in all the pressure chambers **52** are equal to each other.

A case is described above where the cross-sectional area of the common flow channel **55** is the same for all of the pressure chambers **52**, but the present invention is not limited in particular to a case of this kind, and it may also be applied to a case where the cross-sectional area of the common flow channel **55** is not the same for all of the pressure chambers. In a case where the cross-sectional area is not the same in this fashion, the ink supply ports **560** and the ink circulation ports **570** are arranged at positions so that the pressure differential in the ink between the ink supply port **560** and the ink circulation port **570** which are connected to the same pressure chamber **52** is equal, for all of the pressure chambers **52**.

FIG. **2** is a commonly known acoustic circuit model which is equivalent to the principal part of the liquid ejection head **50** shown in FIG. **1** (hereinafter, this mode is also called an "equivalent model"). In FIG. **2**, only one pressure chamber **52** and a portion of the common flow channel **55** corresponding to that pressure chamber **52** are depicted. The amount of ink flowing in a pressure chamber **52** is described below, with reference to this equivalent model.

In FIG. **2**, R**1** is the flow channel resistance on the pressure chamber **52** side (namely, the flow channel resistance from the ink supply port **560**, via the pressure chamber **52**, and up to the ink circulation port **570**), which is sum of the flow channel resistance R_{11} of one ink supply flow channel **56**, the flow channel resistance R_{12} of one pressure chamber **52**, and the flow channel resistance R_{13} of one ink circulation flow channel **57**. R**2** is the flow channel resistance of a portion of the common flow channel **55** corresponding to one pressure chamber **52** (in other words, the flow channel resistance from the ink supply port **560** which is connected to the pressure chamber **52**, via the common flow channel **55**, and up to the ink circulation port **570**).

The equivalent model is constituted by connecting parallel circuits each comprising the flow channel resistance R**1** and the flow channel resistance R**2**, in series. In an equivalent model of this kind, it can be seen that if a pressure is applied to both ends of the flow channel resistance R**2** (in other words, if a pressure is applied to the common flow channel **55** in such a manner that ink flows through the common flow channel **55**), then this means that the same pressure is applied to both ends of the flow channel resistance R**1**, and therefore ink also flows through the pressure chamber **52** which corresponds to the flow channel resistance R**1**. In other words, ink is supplied from the common flow channel **55** to the pressure chamber **52** via the ink supply flow channel **56**, and the ink is returned to the common flow channel **55** via the ink circulation flow channel **57**.

The ratio U**1**:U**2** between the volume of liquid flowing through the common flow channel **55**, U**1**, and the volume of liquid flowing through the pressure chamber **52**, U**2**, is equal to the ratio R**2**:R**1** between the flow channel resistances.

The following Formulas 1 to 4 are used to calculate the flow channel resistances R**1** and R**2**.

In the case of a round tube which has a circular cross-sectional shape as shown in FIG. **3**, the flow channel resistance R is expressed by Formula 1.

$$R = \frac{128\mu l}{\pi d^4} \qquad \text{Formula 1}$$

Here, "μ" is the viscosity of the ink, "d" is the diameter of the flow channel and "l" is the length of the flow channel.

In the case of a flow channel in which the diameter d changes in the lengthwise direction (the x-axis direction), then the flow channel resistance R is expressed by Formula 2.

$$R = \int \frac{128\mu}{\pi\{d(x)\}^4}dx \qquad \text{Formula 2}$$

In the case of a rectangular tube which has a rectangular cross-sectional shape as shown in FIG. **4**, the flow channel resistance R is expressed by Formula 3.

$$R = 2k\mu l\frac{S^2}{A^3} \qquad \text{Formula 3}$$

Here, "μi" is the viscosity of ink, "l" is the length of the flow channel, "A" is the cross-sectional area of the flow channel, and "S" is the total circumference of the flow channel. Furthermore, "k" is a constant which is determined by the aspect ratio ϵ, as expressed by Formula 4.

$$k = \frac{1.5}{(1+\varepsilon)^2\left\{1 - \frac{192}{\pi^5}\varepsilon\left(\tanh\frac{\pi}{2\varepsilon} + \frac{1}{3^5}\tanh\frac{\pi}{2\varepsilon} + \dots\right)\right\}} \qquad \text{Formula 4}$$

Here, the aspect ratio ϵ satisfies the following: ϵ=a/b (where b>a). In other words, it is the ratio of the lengths "a" and "b" of the two edges of the rectangular shape shown in FIG. **4**.

Here, it is considered that the actual design value of the pressure differential applied between the ink supply port **560** and the ink circulation port **570** connected to the same pressure chamber **52** is 5 Pa. If the pressure differential is equal to or greater than this value, then variation arises in the volume of the ink droplets ejected from the pressure chambers **52** and non-uniformities may occur in the image formed on an ejection receiving medium. Furthermore, it is considered that the actual design values are R**1**=1×10^{13} (Ns/m^5) and R**2**=1×10^{9} (Ns/m^5). These values of R**1** and R**2** are selected appropriately when the liquid ejection head **50** is manufactured. In the liquid ejection head **50** shown in FIG. **1**, if the pressure differential is 5 Pa and the flow channel resistances are R**1** and R**2**, then the volume U**1** of ink flowing through the pressure chamber **52** will be 500 pl/s and the volume U**2** of ink flowing through the common flow channel **55** will be 5×10^6 pl/s.

Firstly, considering the value of U**1**, if the flow rate inside the pressure chamber **52** is approximately 500 pl/s, then it is possible to achieve a satisfactory effect in preventing increase in the viscosity of the ink. Next, the value of the U**2** is considered below. In other words, the refilling characteristics is considered below. The volumetric ejection speed for one nozzle at full duty is 4×10^5 pl/s per nozzle, for example. This is the figure in the case of an ejection frequency of 20 kHz and a liquid droplet volume of 2 pl. The volume of ink which flows in the common flow channel **55**, U**2** (=5×10^6 pl/s), is one power of ten greater than volumetric ejection speed per nozzle, which is 4×10^5 pl/s, and is therefore substantially equal to the ink ejection volume of approximately ten nozzles **51** operating at full duty. In other words, even in the case of a liquid ejection head **50** in which ten nozzles **51** are arranged with respect to one common flow channel **55**, the volume of ink lost due to ejection from the nozzles **51** can be supplied (refilled) without giving rise to any delay. Even if nozzles **51** of a greater number than ten are provided with respect to one common flow channel **55**, the effects in assisting the refilling of ink into the pressure chambers **52** are extremely beneficial.

As described above, according to the structure shown in FIG. **1**, it is possible to simultaneously obtain both an effect in preventing increase in the viscosity of the ink in the nozzles **51** and the pressure chambers **52**, and an effect in assisting the refilling of ink into the pressure chambers **52**.

The positional relationship between the pressure chambers **52**, the ink supply flow channels **56** and the ink circulation flow channels **57** is not limited in particular to the positional relationship shown in the basic schematic drawing in FIG. **1**.

Below, the liquid ejection head **50** shown in FIG. **1** will be described in detail, separately with reference to embodiments which respectively have different positional relationships among the pressure chambers **52**, the ink supply flow channels **56**, the ink circulation flow channels **57**, and the like.

First Embodiment

FIG. **5** is a planar perspective diagram showing the principal part of a liquid ejection head **50***a* which is one example of a first embodiment. Furthermore, FIG. **6** shows a cross-sectional view along line **6**-**6** of the liquid ejection head **50***a* shown in FIG. **5**; and FIG. **7** shows a cross-sectional view along line **7**-**7** of the liquid ejection head **50***a* shown in FIG. **5**.

As shown in FIG. **6** and FIG. **7**, the liquid ejection head **50***a* is constituted by sequentially layering together a plurality of plates **31**, **32**, **33**, **34**, **35**, **36**, **37**, **38**, **39** and **40**, from the lower side to the upper side in terms of the vertical direction.

A nozzle **51** is formed in the first plate **31** (nozzle plate) which forms the bottommost layer in the vertical direction. An ink circulation flow channel **57** is formed in the second plate **32** (the circulation flow channel plate). A common flow channel **55** is formed in the third plate **33**, the fourth plate **34** and the fifth plate **35**. An ink supply flow channel **56** is formed in the sixth plate **36**, the seventh plate **37** and the eighth plate **38**. A pressure chamber **52** is formed in the ninth plate **39**. The tenth plate **40** is a diaphragm, which forms the ceiling plate of the pressure chamber **52**. A piezoelectric element **58** is formed on top of the diaphragm **40** to serve as an actuator which changes the volume of the pressure chamber **52** so as to cause ink to be ejected from the nozzle **51**.

Furthermore, in the third to eighth plates **33** to **38**, a nozzle connection flow channel **521** is formed to extend from the pressure chamber **52** until the vicinity of the nozzle **51**. This nozzle connection flow channel **521** can be regarded as a portion of the pressure chamber **52** in the present embodiment. In other words, in the present embodiment, the ink circulation flow channel **57** is connected to the pressure chamber **52**. The flow channel resistance R**12** of the pressure chamber **52** in the equivalent model in FIG. **2** includes the flow channel resistance of this nozzle connection flow channel **521**. FIG. **6** and FIG. **7** show an example where the nozzle connection flow channel **521** is appended to the pressure chamber **52**, but the present embodiment is not limited in particular to a case such as this, and it may also include cases where there is no nozzle connection flow channel **521** and the nozzle **51** is connected directly to the pressure chamber **52**.

It is desirable that the positions of the connections between the ink circulation flow channels **57** and the common flow channels **55** should be in the lower portions of the common flow channels **55** in terms of the vertical direction, as shown in FIG. **7**. If an ink circulation flow channel **57** is connected to a common flow channel **55** at a position to the lower side of the common flow channel **55** in terms of the vertical direction in this way, then gas bubbles inside the common flow channel **55** are not liable to enter from the ink circulation flow channel **57** into the nozzle **51** or the pressure chamber **52**, and therefore ejection abnormalities caused by such gas bubbles are prevented.

FIG. **7** shows an example of a most desirable case where an ink circulation flow channel **57** is connected to the bottommost position of a common flow channel **55**, but the composition is not limited in particular to a case of this kind. The present embodiment also includes any case where the ink circulation flow channel **57** is connected at a position lower than ½ of the height of the common flow channel **55** in terms of the vertical direction.

Furthermore, as shown in FIG. **7**, it is desirable that the ink circulation flow channel **57** should be connected to the pressure chamber **52** (in the present embodiment, to the nozzle connection flow channel **521**) in the vicinity of the nozzle **51**. In other words, a structure is achieved in which the ink is caused to circulate from the vicinity of the nozzle **51** into the common flow channel **55**. By adopting a structure of this kind, a beneficial effect is obtained in that ink of increased viscosity can be circulated with better efficiency.

FIG. **6** shows a case where the ink supply flow channel **56** is connected to substantially the center of the ceiling of the common flow channel **55**, but the present embodiment is not limited in particular to a case of this kind.

FIG. **8** shows in particular an ink supply port **560** and an ink circulation port **570** which are connected to the same pressure chamber **52** in a liquid ejection head **50***b* according to a further example of the present embodiment, and it depicts a cross-sectional perspective view in which a section that is perpendicular to the direction of flow of the liquid in the common flow channel **55** is observed from the upstream side toward the downstream side.

In FIG. **8**, the ink supply port **560** and the ink circulation port **570** which are connected to the same pressure chamber **52** are disposed in substantially diagonally opposite positions, with reference to the axial line **550** which passes in the direction of flow of the liquid in the common flow channel **55**.

The ink which exits from the pressure chamber **52** and passes in the vicinity of the nozzle **51** increases slightly in viscosity. In other words, the ink **77** which returns to the common flow channel **55** from the ink circulation flow channel **57** is in a state of increased viscosity. If this ink **77** of increased viscosity were to enter back into the pressure chamber **52** via the ink supply flow channel **56** and pass again in the vicinity of the nozzle **51**, then the viscosity of the ink would rise yet further. Therefore, as shown in FIG. **8**, the ink supply port **560** (in other words, the position of the connection between the ink supply flow channel **56** and the common flow channel **55**) and the ink circulation port **570** (in other words, the position of the connection between the ink circulation flow channel **57** and the common flow channel **55**) are disposed in substantially diagonally opposite positions in the common flow channel **55**, in order that the ink **77** of increased viscosity does not enter back into the pressure chamber **52**. In this way, the ink supply port **560** and the ink circulation port **570** are connected with the common flow channel **55** in mutually opposing (diagonally opposite) positions.

Since the ink flows inside the common flow channel **55** in a laminar flow, then the ink **77** of increased viscosity which exits from the ink circulation flow channel **57** and is circulated into the common flow channel **55**, and the fresh ink which enters into the common flow channel **55** from the ink supply flow channel **56** do not mix together.

Second Embodiment

FIG. **9** is a planar perspective diagram showing the principal part of a liquid ejection head **50***c* which is one example of a second embodiment. In FIG. **9**, the same reference numerals are assigned to constituent elements which are the same as the constituent elements of the liquid ejection head **50***a* of the example of the first embodiment which is shown in FIG. **5**, and details which have already been described with reference to the first embodiment are not explained further here.

In FIG. **9**, the common flow channel **55** is disposed following the direction of arrangement of a plurality of pressure chambers **52** (e.g. **52***a*, **52***b*, **52***c*). In other words, a plurality of pressure chambers **52** are arranged following the direction of the flow of liquid in the common flow channel **55**. In order to simplify the illustration, FIG. **9** shows only three pressure chambers **52**, in other words, the i^{th} pressure chamber **52***a*, the $(i+1)^{th}$ pressure chamber **52***b*, and the $(i+2)^{th}$ pressure chamber **52***c*, but the number of pressure chambers **52** is not limited in particular to three, and N pressure chambers **52** (where N is an integer equal to or greater than 2) are arranged following the direction of flow of the liquid in the common flow channel **55**.

In FIG. **9**, any two pressure chambers **52** which are mutually adjacent, of the N pressure chambers **52**, are observed in particular. For example, the i^{th} pressure chamber **52***a* and the $(i+1)^{th}$ pressure chamber **52***b*, which are referred to below as the "first pressure chamber" **52***a* and the "second pressure chamber" **52***b*, are observed in particular. Here, the ink supply port **560***b* (second ink supply port) which is connected to the second pressure chamber **52***b* is disposed to the downstream side in terms of the direction of flow of liquid in the common flow channel **55**, in comparison with the ink supply port **560***a* (first ink supply port) which is connected to the first pressure chamber **52***a*. Similarly, the ink circulation port **570***b* (second ink circulation port) which is connected to the second pressure chamber **52***b* is disposed to the downstream side in terms of the direction of flow of liquid in the common flow channel **55**, in comparison with the ink circulation port **570***a* (first ink circulation port) which is connected to the first pressure chamber **52***a*. The positional relationship described above is the same as that of the liquid ejection head **50***a* according to the first embodiment; however, in the liquid ejection head **50***c* according to the present embodiment, in contrast to the liquid ejection head **50***a* according to the first embodiment, the ink circulation port **570***a* (first ink circulation port) which is connected to the first pressure chamber **52***a* is disposed to the downstream side in terms of the direction of flow of liquid in the common flow channel **55**, in comparison with the ink supply port **560***b* (second ink supply port) which is connected to the second pressure chamber **52***b*. In other words, taking the distance between the ink supply port **560** and the ink circulation port **570** which are connected to the same pressure chamber **52** (for example, pressure chamber **52***a*) to be L**1**, and taking the distance between two ink supply ports **560** which are connected respectively to different pressure chambers **52** that are mutually adjacent in the direction of flow of liquid in the common flow channel **55** (for example, pressure chambers **52***a* and **52***b*), to be L**2**, then L**1**>L**2**. This positional relationship is established for all of the pressure chambers **52** which are arranged following the direction of flow of liquid in the common flow channel **55**.

Here, the pressure differential (also called "back pressure differential") between pressure chambers **52** will be described. From the viewpoint of preventing increase in the viscosity of the ink inside the pressure chambers **52**, the pressure differential applied to the common flow channel **55** should be made large, thereby raising the ink flow rate. However, in so doing, the pressure differential between the pressure chambers **52** which are aligned with the common flow channel **55** also becomes large. If the pressure differential between the pressure chambers **52** is large, then variation in the ink ejection volume occurs between the nozzles **51**, and this a cause of non-uniformities in the image. By adopting the liquid ejection head **50** according to the present embodiment, the pressure differential between the ink supply port **560** and the ink circulation port **570** which are connected to the same pressure chamber **52** (this pressure differential corresponds to L**1**) is large, while the pressure differential between ink supply ports **560** which are connected respectively to mutually adjacent pressure chambers **52** (this pressure differential corresponds to L**2**) is small. In other words, "L**1**>L**2**" is satisfied, and therefore it is possible to achieve a small pressure differential between the pressure chambers **52** while maintaining a large ink flow volume inside the pressure chambers **52**.

The positions of the ink circulation ports **570** are not limited in particular to the positions shown in FIG. **9**, and they may be any positions where "L**1**>L**2**" is satisfied.

Third Embodiment

FIG. **10** is a cross-sectional diagram showing the principal part of a liquid ejection head **50***d* which is one example of a third embodiment. FIG. **10** is a cross-sectional diagram viewed in a vertical direction perpendicular to the nozzle surface **510**. In FIG. **10**, the same reference numerals are assigned to constituent elements which are the same as the constituent elements of the liquid ejection head **50***a* of the first embodiment which is shown in FIG. **7**, and details which have already been described with reference to the first embodiment are not explained further here.

In FIG. **10**, the liquid ejection head **50***d* is constituted by sequentially layering together a plurality of plates **31** to **40**, including a nozzle plate **31** which is formed with a nozzle **51**, and a circulation flow channel plate **32** which is formed with an ink circulation flow channel **57**.

Here, the circulation flow channel plate **32** is adjacent to the nozzle plate **31**. In other words, of the plurality of plates **32**, **33**, **34** and **35** which constitute the common flow channel **55**, the ink circulation flow channel **57** is formed in the plate **32** which is nearest to the nozzle surface **510**. Furthermore, in the present embodiment, the common flow channel **55** is formed in contact with the nozzle plate **31**. In other words, the bottom face of the common flow channel **55** is constituted by the nozzle plate **31**. By this means, the thickness of the separation between the common flow channel **55** and the exterior is only the thickness of the nozzle plate **31**, and therefore the common flow channel **55** has a damping function of absorbing cross talk between pressure chambers **52**.

By adopting a composition of this kind, it is possible to circulate the ink from the vicinity of the nozzle to the common flow channel, in such a manner that the effect in preventing increase in the viscosity of ink can be maximized while a damping capacity of the common flow channel **55** with respect to cross-talk between the pressure chambers **52** is obtained.

Fourth Embodiment

FIG. **11** is a cross-sectional diagram showing the principal part of a liquid ejection head **50***e* which is one example of a fourth embodiment. FIG. **11** is a cross-sectional diagram viewed in a vertical direction perpendicular to the nozzle surface **510**. In FIG. **11**, the same reference numerals are assigned to constituent elements which are the same as the constituent elements of the liquid ejection head **50***d* of the third embodiment which is shown in FIG. **10**, and details which have already been described are not explained further here. Furthermore, FIG. **12** shows a horizontal cross-sectional diagram along line **12**-**12** in FIG. **11**.

In FIG. **11**, the ink circulation flow channels **57** are groove sections which are formed by half-etching the circulation flow channel plate **32** in the thickness direction. In other words, the height of the ink circulation flow channel **57** is smaller than the thickness of the circulation flow channel plate **32**.

By adopting a composition of this kind, it is possible to improve the rigidity of the circulation flow channel plate **32** in which the ink circulation flow channels **57** are formed, and therefore handling becomes easier. Furthermore, since the flow channel resistance of the ink circulation flow channels **57** is increased, then it is also possible to increase the ejection efficiency.

Furthermore, as shown in FIG. **1**, the groove sections forming the ink circulation flow channels **57** which are created by half etching are desirably formed in the thickness direction of the circulation flow channel plate **32**, on the side adjacent to the nozzle plate **31**. This is because circulating the ink from the vicinity of the nozzle **51** to the common flow channel **55** increases the effect of preventing increase in the viscosity.

Fifth Embodiment

FIG. **13** is a cross-sectional diagram showing the principal part of a liquid ejection head **50***f* which is one example of a fifth embodiment. FIG. **13** is a cross-sectional diagram viewed in a vertical direction perpendicular to the nozzle surface **510**. In FIG. **13**, the same reference numerals are assigned to constituent elements which are the same as the constituent elements of the liquid ejection head **50***d* of the third embodiment which is shown in FIG. **10**, and details which have already been described are not explained further here. Furthermore, FIG. **14** shows a horizontal cross-sectional diagram along line **14-14** in FIG. **13**.

In FIG. **13** and FIG. **14**, projection-shaped bridge sections **59***a* are disposed in the common flow channel **55** so as to form rigid bodies which surround the ink circulation ports **570**. The height of each bridge section **59***a* is the same as the thickness of the circulation flow channel plate **32**. If the ink circulation flow channels **57** are formed by etching in the circulation flow channel plate **32**, then the bridge sections **59***a* forming rigid bodies are created by leaving the perimeter of each of the ink circulation ports **570** without being etched. They may also be created by half-etching.

Rigidity is obtained in the circulation flow channel plate **32** by means of the bridge sections **59***a* of this kind. Furthermore, if the ink circulation flow channels **57** are formed by half etching as in the liquid ejection head **50***e* according to the fourth embodiment which is shown in FIG. **11**, then it is difficult to achieve good dimensional accuracy of the ink circulation flow channels **57** (in terms of the height in the thickness direction of the plate), whereas in the present embodiment, it is not necessary to form the ink circulation flow channels **57** by half etching, and the height of the ink circulation flow channels **57** is governed by the thickness of the circulation flow channel plate **32**, and therefore the dimensional accuracy of the ink circulation flow channels **57** can be ensured readily.

The rigid bodies are not limited in particular to the bridge sections **59***a* as shown in FIG. **14**. For example, as shown in the horizontal cross-sectional view shown in FIG. **15**, looking at the whole of the circulation flow channel plate **32**, it is also possible to form the spaces each of which surrounds each of the ink circulation flow channels **57** in the common flow channel **55**. More specifically, the bridge sections **59***b* (rigid bodies) are formed in another plate separate from the circulation flow channel plate **32**, and are provided in between each pair of ink supply ports **560** which are mutually adjacent in the common flow channel **55**. In this way, by arranging the bridge sections **59***b* and the ink supply ports **560** at positions which are not mutually overlapping (and by arranging the bridge sections **59***b* so as not to locate between pairs of the ink supply ports **560** and the ink circulation flow channels **57**), inside the common flow channel **55**, then cross-talk waves exiting from the ink supply ports **560** are prevented from striking the bridge sections **59***b* directly. In the present example, the bridge sections **59***b* are each provided exactly midway between two ink supply ports **560**, and therefore the damping effect of the common flow channel **55** with respect to cross talk between the pressure chambers **52** is improved.

In the present example, the bridge sections **59***b* having the same length as the width of the common flow channel **55** are provided as rigid bodies, in the breadthways direction of the common flow channel **55**, but the composition is not limited in particular to a case such as this, and it is also possible to provide the bridge sections **59***b* forming rigid bodies in an oblique direction with respect to the breadthways direction of the common flow channel **55**.

Image Forming Apparatus

FIG. **16** is a schematic drawing showing the composition of a liquid supply system and a maintenance system of an image forming apparatus **80** comprising a liquid ejection head **50** according to an embodiment of the present invention.

In FIG. **16**, the image forming apparatus **80** comprises a liquid ejection head **50**, an ink tank **60** which stores ink to be supplied to the liquid ejection head **50**, an ink introduction tube **61** for introducing ink from the ink tank **60** into the liquid ejection head **50**, an ink extraction tube **62** for leading ink from the liquid ejection head **50** to the ink tank **60**, and a circulation pump **63** provided at an intermediate position in the ink extraction tube **62**

An example is depicted in which the circulation pump **63** is provided to the exterior of the liquid ejection head **50**, but it is also possible to adopt a composition in which the circulation pump **63** is provided in the liquid ejection head **50**. Providing the circulation pump **63** to the exterior of the liquid ejection head **50** as in the present example is desirable in that this composition makes it possible to achieve a large circulation volume.

Furthermore, although not shown in the drawings, rather than mixing the ink which returns to the ink tank **60** from the liquid ejection head **50** via the ink extraction tube **62** directly with the ink inside the ink tank **60**, it is also possible to provide a filter in the ink extraction tube **62** in order to remove dirt from the ink in the ink extraction tube **62**, and furthermore, it is also possible to provide an ink viscosity adjustment unit which performs adjustment in order to return the ink to its original viscosity, by adding water to the ink in the ink extraction tube **62**.

Furthermore, the image forming apparatus **80** also comprises a cap **64** which seals the nozzle surface **510** of the liquid ejection head **50**, and a wiping member **66** which forms a device for cleaning the nozzle surface **510** of the liquid ejection head **50**. The cap **64** is used as a device for preventing the drying of the meniscus in the nozzles **51** of the liquid ejection head **50** during a prolonged idle period without performing ejection, as a device for preventing increase in the viscosity of the ink in the vicinity of the meniscus, and as a suctioning cap for suctioning ink from the nozzles **51** of the liquid ejection head **50**. A maintenance unit including the cap **64** and the wiping member **66** are configured to be able to move relatively with respect to the liquid ejection head **50** by a movement mechanism (not shown), and is moved from a predetermined holding position to a maintenance position below the liquid ejection head **50** as required.

Furthermore, the cap **64** is displaced up and down relatively with respect to the liquid ejection head **50** by an elevator mechanism (not shown). The elevator mechanism is configured such that the cap **64** is raised to a predetermined elevated position so as to come into close contact with the liquid ejection head **50**, and the nozzle face **510** is thereby covered with the cap **64**. A suction pump **67** suctions ink from the nozzles **51** of the liquid ejection head **50** and sends the suctioned ink to a waste ink tank **68** in a state where the nozzle surface **510** of the liquid ejection head **50** is sealed by the cap **64**. A suction operation of this kind is carried out when ink is filled into the liquid ejection head **50** from the ink tank **60** (initial filling), and it is also carried out when removing ink of increased viscosity after the apparatus has been out of use for a long period of time (start of use after long period of inactivity).

FIG. **17** is a block diagram showing the control system of an image forming apparatus **80** comprising the liquid ejection head according to an embodiment of the present invention.

In FIG. **17**, the image forming apparatus **80** chiefly comprises: a liquid ejection head **50**, a communications interface **81**, a system controller **82**, memories **83***a*, **83***b*, a conveyance motor **84**, a conveyance driver **840**, a print controller **85**, a liquid supply unit **86**, a liquid supply control unit **860** and a head driver **87**.

The image forming apparatus **80** has a total of four liquid ejection heads **50**, one for each color of black (K), cyan (C), magenta (m) and yellow (Y).

The communications interface **81** is an image input device that receives image data sent from a host computer **89**. It is possible to use a wired or wireless interface for the communications interface **81**. The image data acquired by the image forming apparatus **80** via this communications interface **81** is stored temporarily in the first memory **83***a* which is used to store image data.

The system controller **82** is constituted by a microcomputer and peripheral circuits thereof, and the like, and it forms a main control device which controls the whole of the image forming apparatus **80** in accordance with prescribed programs. More specifically, the system controller **82** controls units such as the communications interface **81**, the conveyance driver **840**, the print controller **85**, and the like.

The conveyance motor **84** supplies a motive force to the roller and belt, and the like, in order to convey an ejection receiving medium such as paper. The ejection receiving medium and the liquid ejection heads **50** are moved relatively with respect to each other, by means of this conveyance motor **84**. The conveyance driver **840** is a circuit that drives the conveyance motor **84** in accordance with commands from the system controller **82**.

The liquid supply unit **86** comprises an ink introduction channel (reference numeral **61** in FIG. **16**) for introducing ink from an ink tank (reference numeral **60** in FIG. **16**) to a liquid ejection head **50**, an ink extraction tube **62** for extracting ink from the liquid ejection head **50** to the ink tank **60**, and a circulation pump (reference numeral **63** in FIG. **16**).

The liquid supply control unit **86** is constituted by a microcomputer and peripheral circuits of same, and it controls the supply of ink to the liquid ejection head **50**, by means of the liquid supply unit **86**. In the present embodiment, the liquid supply control unit **86** uses the circulation pump **63** of the liquid supply unit **86** as a liquid flow creating device, and performs the liquid flow forming control to control the creation of a liquid flow in the common flow channel **55** of the liquid ejection head **50**.

The print controller **85** generates the data (dot data) on the basis of the image data input to the image forming apparatus **80**. The dot data is necessary for forming dots on an ejection receiving medium by ejecting liquid droplets from the liquid ejection head **50** onto the ejection receiving medium. More specifically, the print controller **85** functions as an image processing device for performing various tasks, compensations, and other types of processing for generating dot data for ejecting droplets on the basis of the image data stored in the first memory **83***a*, in accordance with commands from the system controller **82**, and supplies the generated dot data to the head driver **87**.

The print controller **85** is accompanied with the second memory **83***b*, and dot data and other data are temporarily stored in the second memory **83***b* when image is processed in the print controller **85**.

The aspect shown in FIG. **17** is one in which the second memory **83***b* accompanies the print controller **85**; however, the first memory **83***a* may also serve to accomplish the functions of the second memory **83***b* and may be used instead of the second memory **83***b*. Also possible is an aspect in which the print controller **85** and the system controller **82** are integrated to form a single processor.

The head driver **87** outputs ejection drive signals to the piezoelectric elements **24** of the liquid ejection head **50** on the basis of the dot data supplied by the print controller **85** (in practice, the dot data stored in the second memory **83***b*). By supplying the ejection drive signals output from the head driver **87**, to the piezoelectric elements **24** of the liquid ejection heads **50**, liquid (droplets) are ejected from the nozzles **51** of the liquid ejection heads **50** toward the ejection receiving medium.

Sequence of Processing

FIG. **18** is a general flowchart showing the sequence of one example of an ink refilling process for a liquid ejection head **50**. Here, an example is described in which the ink refilling process shown in FIG. **18** is carried out when the power to the image forming apparatus **80** is switched on (during initial filling), or when ejection has not been carried out for a long period of time (in other words, when use is restarted after a long idle period).

The liquid supply control unit **860** shown in FIG. **17** starts the ink refilling processing shown in FIG. **18** when an ink refilling instruction is issued by the system controller **82**. This processing is carried out by the microcomputer which constitutes the liquid supply control unit **860**, in accordance with prescribed programs.

Firstly, the nozzle surface **510** of the liquid ejection head **50** is sealed with the suction cap (**64** in FIG. **16**) (S**2**).

Thereupon, the circulation pump (**63** in FIG. **16**) is driven in such a manner that the interior of the common flow channel **55** of the liquid ejection head **50** assumes a prescribed pressure (positive pressure) (S**4**); it is then judged whether or not a prescribed time period has elapsed (S**6**); and if the prescribed time period has elapsed, then the driving of the circulation pump **63** is halted (S**8**).

Subsequently, the suction pump (**67** in FIG. **16**) is driven (S**10**); it is judged whether or not a prescribed period of time has elapsed (S**12**); and if the prescribed period of time has elapsed, then the driving of the suction pump **67** is halted (S**14**).

Thereupon, the nozzle surface **510** of the liquid ejection head **50** is wiped with a wiping member (**66** in FIG. **16**) (S**16**). In so doing, the ink refilling process is completed.

The ink refilling process is not limited in particular to the ink refilling process shown in FIG. **19**, but desirably, firstly ink is refilled into the ink circulation flow channel (**57** in FIG. **1**), whereupon ink is then refilled into the pressure chambers (**52** in FIG. **1**).

Furthermore, the circulation of ink from the common flow channel **55** to the ink tank **60** due to the driving by the circulation pump **63** is not limited to being carried out when the power to the image forming apparatus **80** is switched on (during initial filling) or when the apparatus starts to be used after a prolonged idle period. For example, it is also possible to cause ink to circulate only between pages, when the paper is being conveyed, and it is also possible to circulate the ink when it is judged on the basis of the image data that the ejection volume is smaller than a previously determined prescribed value. Furthermore, it is also possible to circulate the ink when the power supply is switched off. A combination of these methods may also be used.

Furthermore, it is desirable that the circulation of ink caused by the driving of the circulation pump **63** should also be carried out during ejection by the liquid ejection head **50** (during image formation). In other words, it is desirable that ink should be made to flow in the common flow channel **55** during ejection by the liquid ejection head **50**.

If a pressure differential arises in this way between the ink supply ports **560** and the ink circulation ports **570** in the common flow channel **55**, during ejection by the liquid ejection head **50**, then a merit is also obtained in that the refilling of ink into the pressure chambers **52** is thereby aided. In other words, a combined effect can be expected in that in addition to preventing increase in viscosity, it is also possible to assist refilling.

If there is no flow of ink during ejection, then the refilling driving force is created by the capillary force of the nozzle **51** sections. In this case, if the flow channel resistance from the ink tank **60** to the pressure chamber **52** is high, then a sufficient flow rate for refilling is not guaranteed, and therefore it may not be possible for the supply to keep pace with the ejection volume. If there is a flow of ink in the common flow channel **55**, then ink is compulsorily replenished to the ink supply flow channels **56** which lead from the common flow channel **55** to the pressure chambers **52**, and this is equivalent to reducing the flow channel resistance between the ink tank **60** and the pressure chambers **52**. Therefore, a positive action on the refilling of ink into the pressure chambers **52** is obtained.

Liquid Ejection Head Having Matrix Structure

FIG. **19** is a plan perspective diagram showing the principal part of a liquid ejection head **50***g* having a matrix structure to which an embodiment of the present invention is applied. FIG. **19** shows an example of a matrix structure comprising a two-dimensional 4×4 arrangement of nozzles, in which four nozzles **51** are arranged in the main scanning direction M (the direction perpendicular to the medium conveyance direction S), and furthermore, four nozzles **51** are arranged in a direction which is oblique with respect to the main scanning direction (the approximate medium conveyance direction S). However, the nozzle configuration is not limited in particular to this matrix structure, and it is possible to provide any number of nozzles **51**, according to requirements.

In FIG. **19**, the liquid introduction port **556** is connected to the ink introduction tube **61** in FIG. **16**, and is thereby linked to the ink tank **60** in FIG. **16** via this ink introduction tube **61**. Furthermore, the liquid extraction port **557** is connected to the ink extraction tube **62** in FIG. **16**, and is thereby linked to the ink tank **60** via this ink extraction tube **62**.

A common flow channel **55** leading from the ink introduction port **556** to the ink extraction port **557** is formed in the liquid ejection head **50**. The common flow channel **55** is constituted by an upstream section **551** which connects to the ink introduction port **556**, midstream sections **552** (pressure chamber connection sections) to each of which a plurality of pressure chambers **52** are connected via ink supply flow channels **56** and ink circulation channels **57**, and a downstream section **553** which connects to the ink extraction port **557**. In the present example, one upstream section **551** and one downstream section **553** of the common flow channel **55** are disposed in the main scanning direction, and a plurality of midstream sections **552** of the common flow channel **55** are disposed following a direction (the approximate scanning direction S) which is oblique with respect to the main scanning direction M (the direction perpendicular to the medium conveyance direction), in other words, they are disposed following the direction of arrangement of pressure chambers **52**. An ink supply flow channel **56** and an ink circulation channel **57** which are connected to the same pressure chamber **52** are connected to the same midstream section **552** of the common flow channel **55**.

Even if it is sought to append a new common flow channel used exclusively for ink circulation (not illustrated), separately from the common flow channel **55** for supplying ink to the pressure chambers **52**, in practical terms, it is difficult to append a new common flow channel of this kind, for reasons of space. This is because a new flow channel which is parallel to the common flow channel **55** for supplying ink must be provided additionally throughout the whole of the liquid ejection head **50**. However, by applying embodiments of the present invention, it is sufficient to append an ink circulation channel **57** locally between the common flow channel **55** and each pressure chamber **52**. In other words, even in the case of a matrix structure as described above, it is possible to obtain the combined benefits of preventing increase in the viscosity of the ink in the vicinity of the nozzles **51** and refilling ink into the pressure chambers **52**, while saving space.

Examples are described above in which ink is ejected, but the present invention is not limited in particular to cases where ink is ejected, and it may also be applied to cases where a liquid other than ink is ejected, for example, a treatment liquid which is ejected before ejection of ink, or the like.

The present invention is not limited to the examples described in the present specification or shown in the drawings, and various design modifications and improvements may of course be implemented without departing from the scope of the present invention.

It should be understood that there is no intention to limit the invention to the specific forms disclosed, but on the contrary, the invention is to cover all modifications, alternate constructions and equivalents falling within the spirit and scope of the invention as expressed in the appended claims.

What is claimed is:

1. A liquid ejection head, comprising:

a plurality of nozzles which eject liquid;

a plurality of pressure chambers connected respectively to the plurality of nozzles;

a common flow channel which is provided to be shared by the plurality of pressure chambers and has a plurality of supply flow channel connection ports and a plurality of circulation flow channel ports;

a plurality of supply flow channels through which the liquid flows from the common flow channel to the plurality of pressure chambers via the plurality of supply flow channel connection ports; and

a plurality of circulation flow channels through which the liquid flow from the plurality of pressure chambers to the common flow channel via the plurality of circulation flow channel ports,

wherein the plurality of supply flow channel connection ports and the plurality of circulation flow channel ports are arranged so that a pressure differential of the liquid between the supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber is equal in respect of all of the plurality of pressure chambers.

2. The liquid ejection head as defined in claim **1**, wherein a distance, in a direction of flow of the liquid in the common flow channel, between the supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber, is equal in respect of all of the plurality of pressure chambers.

3. The liquid ejection head as defined in claim **2**, wherein, taking the distance between the supply flow channel connection port and the circulation flow channel port which are connected to the same pressure chamber to be L**1**, and taking a distance between the supply flow channel connection ports which are mutually adjacent and are connected respectively to the different pressure chambers, to be L**2**, then L**1**>L**2** is satisfied.

4. The liquid ejection head as defined in claim **1**, wherein the plurality of circulation flow channels are connected to lower portions of the common flow channel in terms of a vertical direction.

5. The liquid ejection head as defined in claim **1**, wherein the plurality of supply flow channel connection ports and the plurality of circulation flow channel ports are arranged at substantially diagonally opposite positions of the common flow channel.

6. The liquid ejection head as defined in claim **1**, comprising a plurality of superimposed plates including a nozzle plate in which the plurality of nozzles are formed and a circulation flow channel plate in which the plurality of circulation flow channels are formed, wherein

the circulation flow channel plate is adjacent to the nozzle plate; and

the common flow channel is formed in contact with the nozzle plate.

7. The liquid ejection head as defined in claim **6**, wherein a height of the plurality of circulation flow channels is smaller than a thickness of the circulation flow channel plate.

8. The liquid ejection head as defined in claim **7**, wherein the plurality of circulation flow channels are formed on a side adjacent to the nozzle plate, in terms of a thickness direction of the circulation flow channel plate.

9. The liquid ejection head as defined in claim **6**, wherein rigid bodies are disposed in the common flow channel so as to surround the plurality of circulation flow channel connection ports.

10. The liquid ejection head as defined in claim **6**, wherein rigid bodies are disposed in the common flow channel, and each of the rigid bodies are arranged between the supply flow channel connection ports which are mutually adjacent.

11. A liquid ejection apparatus comprising the liquid ejection head as defined in claim **1**.

12. The liquid ejection apparatus as defined in claim **11**, further comprising a liquid flow creating device which creates a flow of the liquid in the common flow channel while the liquid ejection head performs ejection of the liquid.

* * * * *